# From Muscles to Music

A Festschrift to Celebrate the 60th Birthday of Gunnar Johannsen

Edited by Bernd-Burkhard Borys and Carsten Wittenberg

Kasseler Personalschriften 1

kassel university press

# From Muscles to Music

A Festschrift to Celebrate the 60$^{th}$ Birthday of Gunnar Johannsen

Edited by Bernd-Burkhard Borys and Carsten Wittenberg

Kasseler Personalschriften 1

kassel university press

Borys, Bernd-Burkhard and Wittenberg, Carsten (Ed.)
From Muscles to Music:
A Festschrift to Celebrate the 60th Birthday of Gunnar Johannsen /
Ed. by Bernd-Burkhard Borys and Carsten Wittenberg. – Kassel:
Kassel Univ. Press, 2003. – 282 S.: Ill. – (Kasseler Personalschriften ; 1)

Bibliographic information published by Die Deutsche Bibliothek
Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at http://dnb.ddb.de

ISBN 3-933146-87-9



Design and Setting: Heiko & Philippa, Kassel
Printing and Processing: Unidruckerei der Universität Kassel
Printed in Germany


TAKEMITSU

# Contents

## Tabula Gratulatoria

*Salaheddin Ali, Kassel, Germany*

*James L. Alty, Loughborough, UK*

*Werner Baetz, Kassel, Germany*

*Sabine Borndorff-Eccarius, Oberhausen, Germany*

*Bernd-Burkhard Borys, Vellmar, Germany*

*Guy Boy, Toulouse, France*

*Pietro Carlo Cacciabue, Ispra, Italy*

*Dieter Dey, Bremen, Germany*

*Markus Durstewitz, Toulouse, France*

*Natascha Feder, Vellmar, Germany*

*T. Govindaraj, Atlanta, USA*

*Inge Grote, Zierenberg, Germany*

*Thomas C. Gudehus, Baunatal, Germany*

*Hans-G. Hansel-Deist, Sontra, Germany*

*Oliver Hengstenberg, Berlin, Germany*

*Horst-Peter Hesse, Salzburg, Austria*

*Jens Heuer, Hamburg, Germany*

*Martin Hollender, Heidelberg, Germany*

*Erik Hollnagel, Linköping, Sweden*

*Wolfgang Holzapfel, Kassel, Germany*

*Toshiyuki Inagaki, Tsukuba, Japan*

*Kensuke Kawai, Yokohama, Japan*

*Michael Kobusch, Kassel, Germany*

*Karl-Friedrich Kraiss, Aachen, Germany*

*Christina Kuchta, Vellmar, Germany*

*Alexander H. Levis, Fairfax, USA*

*Anton Matzenmiller, Kassel, Germany*

*Falk Mletzko, München, Germany*

*Neville Moray, Magagnosc, France*

*Ulrich Neuschaefer-Rube, Kassel, Germany*

*Stephan Neuschaefer-Rube, Kassel, Germany*

*Reiner Onken, Neubiberg, Germany*

*M. M. (René) van Paassen, Delft, The Netherlands*

*Horst Paul, Ahnatal, Germany*

*William B. Rouse, Atlanta, USA*

*Andrew P. Sage, Fairfax, USA*

*Johannes Schwinn, Kassel, Germany*

*Thomas B. Sheridan, Cambridge, USA*

*Yu Shibuya, Kyoto, Japan*

*Henk G. Stassen, Delft, The Netherlands*

*Willi Stein, Wachtberg-Werthhoven, Germany*

*Gerd Strätz, Kassel, Germany*

*Gunilla A. Sundström, Charlotte (NC), USA*

*Martin Suske, Kassel, Germany*

*Markus Tiemann, Wedel, Germany*

*Andreas Völkel, Kassel, Germany*

*Ingo Wagner, Kassel, Germany*

*Carsten Wittenberg, München, Germany*

*Frank Wirth, Felsberg, Germany*

*Philip Zerweck, Kassel, Germany*

# Sixty, suddenly ...

"And suddenly you are 60 ..." – with these words Gunnar Johannsen invited colleagues and friends to his birthday party in September 2001. This anniversary – officially in December 2000, but celebrated nine month later – was accompanied by two other important events: The *8th IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems* and the *Workshop on Supervisory Control in Engineering and Music*.

The *Eighth Symposium* is important to mention here, because it is (like the first and several others) organized by Gunnar Johannsen and (like the first and no other yet) located in Germany.

The *Engineering and Music Workshop* (maybe, we will call it the 1st in the future) is important to mention here because it resembles some of the recent changes in the field of Human-Machine Systems.

The shop floor worker left his previously manual controlled machine and moved to a distant centralized control room. The workload changed from muscles to brain. At the same time, the close contact to work with its sound, vibrations, visions, and smells (of cause: also its dirt, heat, and danger) was lost: Today's control rooms are clean, silent, distant, and safe.

Much work was performed at Gunnar Johannsen's *Laboratory for Human-Machine Systems* at the University of Kassel from the mid-80ies to the mid-90ies to support operators in their distant control rooms as well as pilots in their highly automated cockpits to build a suited mental model out of the information perceived from computer-generated displays. During the last years, however, the dramatic increase in processor speed and memory size accompanied by decreasing prices for computer systems and components made the multimedia computer a standard on the home and entertainment sector. This development will bring elements from multimedia, games and entertainment, and finally musical performance also to the process control room. Multimedia and music may bring back the close contact to the process that had been lost before; operators' attention will shift from displays to music.

The title of this book – *From Muscles to Music* – should resemble these changes. Changes, that accompanied the life of Gunnar Johannsen and changes that were initiated by him. Thus, it was not suddenly but a process from a first personal meeting of some of the key figures of human-machine systems in Urbana-Champain 1976 (and the *International*

*Symposium on Monitoring Behavior and Supervisory Control* in Berchtesgaden in the same year, see the Chapter of Henk Stassen in this book) to these three events 25 years later were the HMS community will meet.

Long before, however, we started this endeavour of compiling a Festschrift that should give an overview of his work, seen with the eyes of people who know him. This would not be possible without the support of many of his friends and colleagues that contributed to this *Festschrift* and we thank all authors who supported this work.

Another important change is the global connectivity and accessibility of worldwide information. This changes the structure of work organizations and finally of society. Guy Boy calls it *From Army to Orchestra* in his contribution to this book, mentioning that the availability of information to everybody is a key issue in these coming changes. From this background, this *Festschrift* for Gunnar Johannsen is also an indicator of changes as it the first publication compiled in his Laboratory for Human–Machine Systems that is available on–line and distributed by the publisher via the Internet.

As professionals in the field of human–computer interaction, we know, on the other hand, about the drawbacks of the virtual world. Consequently, this book is also available as a real, conventionally printed book. This would not have been possible without significant financial assistance and we, editors and authors, want to thank Professor Dr. phil. Heidi Krömker (Technical University of Ilmenau, formerly Siemens AG, Corporate Technology – User Interface Design, München), Dipl.–Ing. Ulrich Jonas (RESOTEC Realtime Software GmbH, Baunatal), and Dr. Wolfgang Gottlieb (DaimlerChrysler Research Centre, Berlin) for their kind support.

*Kassel and München, September 2001*

*Bernd–Burkhard Borys and Carsten Wittenberg*

## The Sponsors

Printing of this book was made possible with financial contributions from

- Siemens AG
  Corporate Technology – User Interface Design
  Otto–Hahn–Ring 6
  81730 München, Germany
  http://www.siemens.com
- RESOTEC Realtime Software GmbH
  Eisenstraße 7
  34225 Baunatal, Germany
  http://www.resotec.com
- DaimlerChrysler AG
  70456 Stuttgart, Germany
  http://www.daimlerchrysler.com

Thank you!

# Preface

*Anton Matzenmiller*
*Dean, Department of Mechanical Engineering*
*University of Kassel*

Anton Matzenmiller is Professor for Computational Mechanics and Dean of the Department of Mechanical Engineering of the University of Kassel.

This volume is dedicated to Prof. Dr.-Ing. Gunnar Johannsen on the occasion of his 60th birthday. The book contains papers written by his friends in the field of human-machine systems.

Dr. Gunnar Johannsen founded the Systems Engineering and Human-Machine Systems Group after he was appointed professor and joined the faculty of Mechanical Engineering at the University of Kassel in 1982.

The group with its Laboratory for Human-Machine Systems is one of the units of the Institute for Measurements and Automation (IMAT). Dr. Johannsen served as dean of mechanical engineering in 1987 / 1988. We all appreciate his many activities for the department of mechanical engineering in Kassel.

The study of human-machine systems and systems engineering has become part of the curriculum for engineering education in Kassel.

The research of Gunnar Johannsen is in the field of task analysis and knowledge based systems, cognitive systems engineering, design and evaluation of human-machine interfaces just to name a few of his areas of interest. His research is in the fast developing topics of cognitive science, ergonomics, systems engineering, and information technology. He applies his models and methods for control to technical systems like helicopters, power plants, chemical plants, robots, and traffic guidance systems.

His research activities led him to longer stays at the University of Illinois at Urbana Champaign, USA in 1977-1978, to the Kyoto Institute of Technology and the Kyoto University, Japan in 1995, and to the Technical University in Vienna, Austria 1999. He is author of the monograph "Mensch-Maschine-Systeme" and the scientific editor of the international journal "Monitoring Behavior and Supervisory Control". He is the director of the $8^{th}$ symposium on "Analysis, Design and Evalation of Human-Machine Systems" of the International Federation of Automatic Control (IFAC) at Kassel in September 2001.

# To Gunnar Johannsen – Celebrating his recent 60th Birthday and his Long Term Commitment to *Systems Engineering and Human-Machine Systems* at Kassel University

*Wolfgang Holzapfel*

*Director, Institute of Measurement and Automation*

*University of Kassel*

In December 1982, almost coinciding with his 42nd birthday, Gunnar Johannsen started from scratch leading the new branch *Systems Engineering and Human-Machine Systems* of the Department of Mechanical Engineering at Kassel University. During the following years he has successfully built up and run teaching and research in his scientific field.

In this festschrift, dedicated to his 60th anniversary, his scientific significance and reputation are mirrored in contributions by distinguished international researchers.

It is not an overstatement to say that Gunnar Johannsen has very successfully contributed towards leading his field of research to international recognition by further developing this fairly new scientific discipline. Working alongside in a friendly and cooperative atmosphere in our two adjacent fields at the Institute of Measurement and Automation, I can competently acknowledge his constructive work and his achievements, building up an extremely good reputation for his branch.

His field of research has a fascinating multidisciplinary character and, in addition, it is clearly application-orientated. Therefore, his research team consists of students and graduates of mechanical and electrical engineering as well as information scientists, psychologists and designers who all successfully cooperate for the benefit of the common tasks.

Under these favourable conditions, graduated students and doctorate candidates can acquire both a broad and thorough qualification and grow to be successful scientists in their later professional life. Quite a few of his former students are now working in responsible positions.

Gunnar Johannsen has written numerous articles on the subject of Human-Machine Systems and related problems in esteemed national and international technical magazines and is the author and editor of several specialist publications. He was responsible for the organization of numerous international IFAC congresses.

Various universities and research institutes from abroad appreciated his work so much that they invited him for extended researches. Gunnar Johannsen succeeded in acquiring considerable financial support for his research projects, particularly from the German Society of Research (DFG) and the European Community. For many of those projects he and his team cooperated with industrial partners and national and international research institutes. Thus he has ensured employment and further qualifications for many young scientists on a broad level.

For the coming years, the members of the Institute of Measurement and Automation sincerely wish Gunnar Johannsen happiness and welfare for his personal life as well as for the continuation of his creative and successful work.

Wolfgang Holzapfel received his PhD (1970) and his qualification as a university lecturer (1978) at the faculty of Mechanical Engineering at the Technical University of Berlin. From 1967 to 1972 he and Gunnar Johannsen worked as research assistants at the Institute for Flight Guidance and Air Traffic at Berlin University. From 1976 to 1980 Holzapfel was the head of Avionics with Honeywell, Germany. Since 1980 he has been a full professor for measurement science at Kassel University. In 1988 together with Gunnar Johannsen he founded the Institute for Measurement and Automation which he has managed as the director since then. His activities in teaching and research deal with measurement, sensors, optics, signal and image processing. Holzapfel is a member of several scientific and engineering societies (SPIE, IEEE, VDI/VDE).

# On the Contributions of Gunnar Johannsen to Human–Machine Systems Engineering, Cognitive Ergonomics, Human–Computer Interface Design and Human–Centered Automation

*Andrew P. Sage*

Gunnar Johannsen was born in Hamburg, Germany, in 1940. He received his Dipl.–Ing. degree in 1967, with a major in communication and information engineering from the Department of Electrical Engineering, and the Dr.–Ing. degree in 1971, with a major in flight guidance and manual control from the Department of Transport, at the Technical University of Berlin, Germany. In 1980, he habilitated, through receipt of the Dr. habil. degree and became Private Docent in the teaching area of human–machine systems of aeronautics and astronautics in the Department of Mechanical Engineering at the Technical University of Aachen Germany. In addition to this technological education, he studied music for three years within the sound engineering curriculum at the University School of Music, Berlin Germany. He has continued this ancillary love of music and his contributions to music and the arts are documented elsewhere in this volume.

From 1967 to 1971, he was a research assistant in the Institute of Flight Guidance, Technical University of Berlin. From 1971 to 1982, he was division head in the Research Institute for Human Engineering near Bonn, Germany. During much of this time, 1974 through 1982, he was also a lecturer of manual vehicle control as the Technical University of Aachen Germany.

The major long term professional position for Professor Johannsen is as University Professor of Systems Engineering and Human–Machine Systems, and Head of the Laboratory for Systems Engineering and Human–Machine Systems in the Institute for Measurement and Automation of the Department of Mechanical Engineering in the University of Kassel, Germany. He has held this position since 1982.

During the years 1977–1981, he was a visiting faculty member in the Department of Mechanical and Industrial Engineering and in the Coordinated Science Laboratory of the University of Illinois at Urbana–Champaign, USA, where he also held an appointment as adjunct associate professor. He has also held a number of other visiting appointments. For example, from April to October 1995 he was recipient of a Japanese–German Research Award granted by JSPS, the Japan Society for the Promotion of Science, working on a research project in Knowledge Based Multi–Human Machine Interfaces at the Kyoto Institute of Technology and at Kyoto University, Japan.

Both through the many professional visits he has made throughout the world and through the large number of professionals visiting his university, there have been numerous opportunities for strong cross fertilization and interaction with many of the best contemporary minds in areas of interest to Professor Johannsen. His research interests are in human information processing, multimodal perception, cognitive systems engineering, manual and supervisory control, problem solving, human error, mental workload, task and knowledge analyses, integrated automation, human–machine function allocations, decision support systems, human–machine interface design, multimedia interfaces (2–D and 3–D graphics, hypertext, video, sound, music), multi–human machine interaction, audio and music technologies, co–operative work, knowledge–based systems, software systems engineering, and information management – with applications in such domains as traffic systems, aircraft, chemical plants, power plants, cement plants, as well as information systems in public, service and consumer sectors.

Under Gunnar's leadership, the teaching activities The Systems Engineering and Human–Machine Systems Group at the University of Kassel have interests and accomplishments in all major subjects of systems engineering and human–machine systems. The research areas of the Laboratory for Systems Engineering and Human–Machine Systems involve four major categories:

- human task performance and knowledge analyses;
- cognitive systems engineering;
- design and evaluation of human–machine interfaces; and
- design and evaluation of knowledge–based decision support systems.

Thus, his major interests and those of his group involve a mixture of cognitive science and ergonomics, systems engineering, and software and information engineering. Engineers of very different disciplines – including computer scientists, systems engineers, and psychologists – work together in the Laboratory.

Gunnar's research leadership at his university has resulted in many documented achievements for himself as well as for the members of his team. He has personally made very significant and successful contributions to research and scholarship in human machine systems in several application domains and has achieved much international recognition for

Andrew P. Sage was Lawrence R. Quarles Professor of Engineering Science and Systems Engineering at the University of Virginia 1974–84 and the first Chair of the Systems Engineering Department. In 1984 he became First American Bank Professor of Information Technology and Engineering at George Mason University and the first Dean of the School of Information Technology and Engineering. He is an elected Fellow of the Institute of Electrical and Electronics Engineers (IEEE), the American Association for the Advancement of Science (AAAS), and the International Council on Systems Engineering (INCOSE). He received several outstanding awards. prizes and medals e.g. from IEEE, IEEE Systems, Man, and Cybernetics Society and ASEE. He was editor of the IEEE Transactions on Systems, Man, and Cybernetics 1972–98 and of the IFAC Journal Automatica 1981–96. He is currently editor of the John Wiley textbook series on Systems Engineering, the INCOSE Wiley journal Systems Engineering, and the journal Information, Knowledge, and Systems Management. He was President of the IEEE Systems, Man, and Cybernetics Society 1984–85 and Chair of Section M (engineering) of the AAAS 1990.
His current interests include systems engineering and management efforts in a variety of application areas.

these efforts. This research has been performed over a period of more than 30 years and has considerable breadth and depth. His research is, methodologically, very interdisciplinary and transdisciplinary in nature. It has great relevance to systems engineering, cognitive science and ergonomics, and software and information engineering. The application domains of his research and development projects dealt with such dynamic technical systems (machines) as aircraft, power plants, chemical plants, cement plants, robots, automobiles, aircraft guidance systems, telematics and information management systems.

His laboratory at Kassel is now celebrating its 15$^{th}$ Anniversary. The Laboratory co-operates successfully with a large number of industrial and academic partners, with the industrial partners mainly from countries of the European Union but also including world wide contacts, and with numerous academic partners throughout Europe, Russia, the USA, Canada, Japan, Korea, China, and Australia. Several international conferences were organized by members of the Laboratory, particularly the IFAC Symposium on Analysis, Design and Evaluation of Man–Machine Systems in 1985 and 1989, the European Annual Conference on Human Decision Making and Manual Control 1993 and 1997, the IFAC Conference on Integrated Systems Engineering 1994, and the 8th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design, and Evaluation of Human–Machine Systems in September 2001.
Among the many research projects of the laboratory, the following might be noted.

1. *ESPRIT P600* was a one–year pilot study in 1984 / 85, consisting of a user survey and a literature survey. It was undertaken to identify the 'real' operator problems associated with process supervision and control systems, as well as the possible technical solutions to these problems. The user survey pointed to opportunities in the fields of knowledge processing, human–computer interaction, and cognitive modeling for solving these problems.
2. *GRADIENT* was an ESPRIT project of the EU (European Union, Brussels) in the area of Advanced Information Processing. The objectives of this 100 person year project which took place over the five–year period 1985–1990, included investigation of the use of knowledge based systems to support the operator of industrial process supervision and control systems, primarily to enable the operator to conduct an intelligent graphical dialogue with the system. The GRADIENT project considered functions needed to support users in these tasks and resulted in the development of several specific advances this area.
3. *Error–Tolerant Control Input Systems.* In this two year project, a model of the tasks to be performed by a pilot was developed. This model runs in parallel to the execution of tasks and checks the consistency of the inputs of the pilot. The pilot is also allowed to select separate parts of the model, which are to be performed automatically, thereby enabling freedom of choice relative to the degree of automation support. This system was implemented in a fixed–base flight sim-

ulator and experimentally validated with professional pilots in a navigation task scenario.

4. *FANSTIC*, or Future Air Traffic Management, New Systems, and Technologies Integration in Cockpit. The main objectives of FANSTIC were to increase airspace capacity while maintaining or improving safety, to optimize crew workload, and to reduce operational costs. The implications of changes in Air Traffic Management expected for the future were evaluated.
5. *Support of Fault Management Tasks.* The main aim of this four year research project was to enable human operators to better verify proposed solutions to detected faults within the context of related knowledge, thereby resulting in very flexible human–machine co–operation.
6. *Information Presentation in the Visual Periphery.* In this project, a new approach was developed for the presentation of system parameters of helicopters in the peripheral visual field. Simulator experiments were used to show that the perception of peripherally arranged information can be improved significantly by means of new dynamic display components. Active professional pilots were involved in the design, refinement and validation of the display concept. The results of this project indicated that the diagnosis of failures in the cockpit can be facilitated and the distribution of the necessary information over the whole visual field can be achieved.
7. *Participative Design.* This four year, 1992–1996, project concerned the interactive design and evaluation of operator interfaces. Different methods for user interface design in process supervision and control engineering were developed that allowed human operators to participate interactively in the design process itself. The methods and techniques developed during this project were evaluated and tested with a simulated chemical distillation process developed at the Institute of System Dynamics and Control Engineering of the University Stuttgart.
8. *Advanced Man–Machine Interfaces for Industrial Process Control Applications.* This project took place during 1993 to 1996 and was supported by the European Union in Brussels. Knowledge based human–machine interfaces for supervision, and guidance and control, of dynamic technical systems in power plants and cement industries were developed. These interfaces contain graphical presentation interfaces, knowledge–based dialogue, tracking interaction and explanation components, as well as technical systems and user models. The prototypes have been tested and evaluated, first with simulators in the laboratory and later, under real conditions in field studies.
9. *Process Visualization using Means-Ends Hierarchies.* In this project, alternative interfaces were developed for a cement grinding mill and a steam generator of a

fossil fuel power plant. These interfaces were developed using two relatively novel techniques, Multilevel Flow Modeling (MFM), developed by Lind, and Ecological Interface Design (EID) by Vicente and Rasmussen. Application of these techniques results in interfaces that are an alternative for the current methodologies of display design. Current designs show a topological view, for example a synopsis of the plant or of a part of the plant. Such a view shows the connection between various components, but not the functional relation between the components. MFM and EID both use a means-ends hierarchy to visualize the process. In a means-ends hierarchy, the ends are the goals that must be obtained and the means are the ways to obtain those goals. This potentially results in improved insights into the functioning of the plant, better fault diagnosis and reduction of operator learning time.

10. *Robust Human-Machine Interaction.* This EU supported collaborative research project taking place from 1994 to 1996, brought together researchers from six European countries who shared an interest in addressing issues in the design of Human-Machine Systems.
11. *DIAMANTA.* The goal of this EU supported project, taking place in 1995 and 1996, was to confirm the suitability of a software development methodology DIADEM (Dialogue Architecture and Design Method) as a means of developing graphical user interfaces that inherently satisfy user needs. The project is important as user interface development has become more and more an important economic factor for software development companies. Experience shows that the user interface software requires about 20% to 50% of the total software development costs. On the other hand, a well-designed user interface improves the usability of the product and, by this, the efficiency of its use and its acceptance by the users. The project results provide support to user interface development in three major tasks: defining roles of humans, including tasks and sequences of activities; developing graphical formalisms to support information exchange between humans; and identifying a basic set of rules for optimum human-machine interfaces. This developed process allows adaptation to specific application and development environments.
12. *Approximate Knowledge-Based Process Visualization.* This research concerned fuzzy logic for achieving user-oriented human-machine interfaces in process control. It concerned a novel design technique for the construction of human-machine interfaces applied to a distillation column. It allowed for increased user orientation through development of human-machine interfaces that were adapted to the cognitive structures of human operators. Fuzzy logic was used to translate natural language procedures acquired from operators into

objects in a knowledge base that enabled visualization of approximate symbolic technical system values, thereby enabling technical systems to be controlled from different viewpoints.

13. *Virtual Process Visualization.* This research project is based on the observation that process control is often characterized by centralization and estrangement of the human supervisory controller. Often today, more and more processes have to be controlled and supervised by fewer operators. The aim of this project is development of a concept and visualization techniques from the virtual reality, implemented as virtual process elements, that enable objects to be modeled based on typical manifestations. This process visualization supports formation of a correct mental model for planning of actions by the operator. Visualization of process variables and relations between process elements, such as time dependencies, are needed for correct supervision and control of processes. A user interface for supervision and control of a distillation column is implemented in this project and its efficacy evaluated.
14. *Situation-Dependent Human-Machine Interface.* This interdisciplinary research project started in 1996 and its major objective is qualitative improvement of human–machine interaction by means of a dynamic representation of technical systems involving supervision and control systems software. The objective of this project is the development of a task-oriented human–machine interface concept for the integration of presentation techniques and knowledge structures, and its testing and evaluation through a use case.
15. *Cooperative Airport Operations.* The objective of this project, supported by the German Research Council since 1997, is optimal realization of flight and dispatching operations on a modern commercial airport under the constraints of extant airport capacities. It seeks optimal accomplishment of airport operations through coordinating actions of all the involved operators and use of required resources in an optimal manner. There are major needs for information presentations decision support systems, particularly during heavy air traffic or in exceptional situations, in efforts of this sort in order both to reduce the mental stress of the operators to an acceptable level and to guarantee optimal performance of the airport operations.
16. *Multimedia Process Control Room.* The centralized control rooms of large industrial plants have often separated people from the processes they should control. Multimedia equipment can bring operator effectively back into the plant while bodily keeping him in a comfortable and safe control room. This involves video and audio transmission from process components as well as sights and sounds artificially generated from measurements. Groupware systems support interac-

tion between operators, engineers, and managers in different locations are also included. The resulting Experimental Multimedia Process Control Room is comprised of high-performance graphics workstations, and such multimedia periphery as video, audio and teleconferencing equipment and vibration and three-dimensional sound generation systems. The resulting control room will be used for several future research projects.

One of Dr. Johannsen's truly major research and scholarly accomplishments has been the demonstration that the need for improved human-machine communication increases, rather than decreases as is often thought, with increased amounts of automation. High levels of safety, performance, and efficiency have been achieved by means of the increased use of automatic control. However, increased automation does not replace the human users who necessarily must interact with machines, but shifts the location of the interface between both. As part of an automated system, a machine becomes more a complex element in a system than is the case with less automation. This leads to more sophisticated structures of supervisory control. Higher complexity and more sophisticated control structures require improved quality of communication and co-operation between humans and machines. He has continuously contributed over three decades to a better understanding of the complicated interactions between human and machine, human and automation, and human and computer. His influence in industrial applications was significantly supported by cooperative efforts with a large number of companies and consortia associated with several European research and development projects.

As also indicated in the foregoing commentary, Gunnar is also a successful Educator. He teaches courses in Systems Engineering, Human-Machine Systems, Knowledge-Based Systems, Process Supervision & Control Engineering, Human-Computer Interaction, Analysis and Evaluation Methods, and Modeling Techniques. It is especially notable that Gunnar wrote the first comprehensive text book on Human-Machine Systems written in German. It was published by Springer-Verlag, Berlin in 1993.

It would be impractical to document the entire list of scholarly accomplishments and publications of Dr. Johannsen. It is perhaps fitting here to conclude these observations with a listing of some of the more relevant of these, with a brief commentary on what are personally regarded as the three most significant of these. Arguably from among his many scholarly and research papers, the three following are most notable.

Johannsen, G., "Towards a new quality of automation in complex man-machine systems,". *Automatica*, Vol. 28 (1992), pp. 355 – 373. Applicability of the human-centered approach towards automation is demonstrated. This is achieved by means of an integrated conceptual structure and a mathematical framework for describing the human-automation synergism in technical systems, based on an extended User Interface Management System (UIMS) to dynamic tasks. Four case studies are elaborated, including heuristic control of industrial processes.

Johannsen, G., „Cooperative human–machine interfaces for plant–wide control and communication," In, J. J. Gertler (Ed.) *Annual Reviews in Control*, Vol. 21. Oxford, Pergamon, Elsevier Science, 1997, pp. 159–170. Human–machine interfaces for cooperative supervision and control by several human users, either in control rooms or in group meetings, are considered. The information flow between the different human users, and their overlapping information needs, are explained. The case study example of a cement plant illustrates this in detail.

Johannsen, G., „Knowledge based design of human–machine interfaces," *Control Engineering Practice*, Vol. 3 (1995), pp. 267–273. Cooperation and communication among different people have become more and more important for industrial, transportation, and service sectors. The design principles and the components of human–machine interfaces are presented, including such issues as user participation, traditional and knowledge–based components, and multi–media.

But, these are only three among many works of significance. These include, but are surely not limited to the following:

Johannsen, G., Mensch–Maschine–Systeme (Human–Machine Systems) Berlin, Springer, 1993

Johannsen, G., Integrated systems engineering – The challenging cross–discipline, Control Engineering Practice, Vol. 6 (1998)

Johannsen, G., S. Ali, and R. van Paassen, Intelligent human–machine systems. In: S. Tzafestas (Ed.), Methods and Applications of Intelligent Control. Dordrecht, Kluwer, 1997, pp. 329–356

Johannsen, G., Conceptual design of multi–human machine interfaces, Control Engineering Practice, Vol. 5 (1997), No. 3, pp. 349–361

Johannsen, G., Computer–supported human–machine interfaces, Journal of the Society of Instrument and Control Engineers (SICE) of Japan, Vol. 34 (1995), pp. 213–220

Johannsen, G., A. H. Levis, and H. G. Stassen, Theoretical problems in man–machine systems and their experimental validation, Automatica, Vol. 30 (1994), pp. 217–231

Fejes, L., G. Johannsen, and G. Straetz, A graphical editor and process visualisation system for man–machine interfaces of dynamic systems, The Visual Computer, Vol. 10 (1993) 1, pp. 1–18

Johannsen, G. and J. L. Alty, Knowledge engineering for industrial expert systems, Automatica, Vol. 27 (1991), pp. 97–114

Stassen, H. G., G. Johannsen, and N. Moray, Internal representation, internal model, human performance model and mental workload, Automatica, Vol. 26 (1990), pp. 811–820

Alty, J. L. and G. Johannsen, Knowledge based dialogue for dynamic systems, Automatica, Vol. 25 (1989), pp. 829–840

Borys, B.–B., G. Johannsen, H.–G. Hansel, and J. Schmidt, Task and knowledge analysis in coal–fired power plants, IEEE Control Systems Magazine, Vol. 7 (1987) 3, pp. 26–30

Johannsen, G., J. E. Rijnsdorp, and A. P. Sage, Human system interface concerns in support system design, Automatica, Vol. 19 (1983), pp. 595–603

Johannsen, G. and W. B. Rouse, Studies of planning behavior of aircraft pilots in normal, abnormal, and emergency situations, IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC–13 (1983), pp. 267–278

Johannsen, G. and T. Govindaraj, Optimal control model predictions of system performance and attention allocation and their experimental validation in a display design study, IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC–10 (1980), pp. 249–261

Sheridan, T. B. and G. Johannsen (Eds.), Monitoring Behavior and Supervisory Control, New York, Plenum Press, 1976, pp. 538

In recognition of his many achievements, Dr. Johannsen was elected a Fellow of the Institute of Electrical and Electronics Engineers effective January 2000. I had the honor of nominating Dr. Johannsen for this most deserved award which represents a fitting compliment to his many other recognitions, and this commentary is based in large part upon the material gathered for this nomination. The overall and simple summary to this commentary must surely be **"Well Done Gunnar."**

## Gunnar Johannsen's Vision on the Human Control of Complex Systems

*Henk G. Stassen*

Henk Stassen is Professor and former Head of the Man–Machine Systems Group of Delft University of Technology and is one of the oldest friends of Gunnar Johannsen. However, you may read yourself ...

During the academic year 1976–1977 I served as a visiting faculty member at the Massachusetts Institute of Technology at Tom Sheridan's Machine Systems Laboratory. During that period I decided to pay a visit to the University of Illinois at Urbana–Champain, Ill., USA, in order to meet one of Tom's old students Bill Rouse. It was there, that I met for the first time a young German scientist working in the field of Man–Machine Systems, Gunnar Johannsen, who spent a year as a visiting lecturer at the Department of Mechanical and Industrial Engineering and as a visiting research associate professor at the Coordinated Science Laboratory. Gunnar's interest was, at that moment, the development of a nonlinear model of human, manual control behaviour in traffic (Johannsen and Rouse, 1979). During the eighties his interest moved from Manual to Supervisory Control (Johannsen, Rijnsdorp and Sage, 1983) ending in the nineties with research on the design of knowledge–based and intelligent human–machine interfaces (Alty and Johannsen, 1989, Johannsen and Alty, 1991). Johannsen has shown to be enthusiastic about the application of informatics and multimedia techniques in the field of man–machine systems. His interest is very broad, and covers among others the process industry, the control of power plants, as well as the control of any type of vehicles.

Johannsen is a system and control engineer, who is convinced of the limitations of the human operator as well as those of the automatic control of complex industrial systems. He is especially interested in the exact balance between the capabilities of the human being and the machine. His research was not only fundamentally oriented. Many projects were applications of his knowledge in a multidisciplinary approach. It was Johannsen who promoted the concept of human–centered design and who was aware of the relation between the classical Man–Machine Systems and the Human Reliability Analysis.

He showed his passion for music already in 1960 when he followed an additional, secondary university study for sound engineer at the University of Berlin. So, his interest is not only in the technical sciences, in the Netherlands called the β–sciences, but also in the α– and γ–sciences. Therefore, it is not surprising that at the end of his professional career his love for music became a part of his professional activities. In 1998 at the 7th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design, and Evaluation of Man–Machine Systems he enlightened a plenary session on Kansei Science and Man–Machine Interaction in the Performing Arts: A first direct relation between science and arts (Oohashi and Nishina, 1998).

Here it is worthwhile to make a comment on what happened in The Netherlands. In 1998 it was exactly 150 years ago that the Royal Dutch Academy of Sciences and Arts was established. 50 years later, one decided to restrict the activities of the Royal Dutch Academy of Sciences and Arts only to the sciences. Then, in the year 1998, on the 100th anniversary of the Royal Dutch Academy of Sciences, a symposium was held on the contribution of arts to science: The final conclusion was that it was very worthwhile to add the arts again as a field of interest of the academy (KNAW, 2000). Johannsen, being the chairman of the 8th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design, and Evaluation of Man–Machine Systems, did take the opportunity to organise directly after the symposium a workshop on the Human Supervision and Control in Engineering and Music. At this four–day workshop he was able to get participants for a variety of disciplines. The disciplines involved musicology, computer music, composition, musical performance at the one hand, and disciplines such as engineering, computer science and psychology at the other. The workshop might become a new trend in the multidisciplinary field of human–machine interaction. The broad interests in the $\alpha$–, $\beta$– and $\gamma$–sciences characterizes the man Gunnar Johannsen.

Personally, I appreciate his multidisciplinary approach, since I strongly believe that progress in future will be at the boundaries of many different disciplines. However, my interests are not in music – I do not understand music very well – but I see the challenge in the integration of engineering at the one hand and the biology application area of medicine at the other. I have tried several times to encourage Johannsen to start a transfer of his knowledge of manual and supervisory control to the field of biomedical engineering, but I never succeeded in doing so. I am convinced that many problems in biomedical engineering will yield analogous difficulties such as the different research approaches and methodologies, cultural and ethical differences (Stassen, 2000) as will be recognized in the integration of engineering and music. It is amazing to see how well knowledge in the field of manual and supervisory control can be transferred to the biomedical field (Stassen, 2001). Moreover, it is important to realise that the biomedical field is a growing field of interests for society, industry and research institutes (CAETS, 1999). I would like to emphasize this important factor. The economic growth of the non–biotechnological industry is estimated to be about 2% per year, that of the biomedical technology will be about 7%, whereas the growth in the field of tissue engineering is estimated to be about 20% (CAETS, 1999). The facts, and my personal interests, make that I would like to focus the attention of the man–machine systems discipline to enter the field of biomedical engineering. Many examples can be given of very interesting man–machine system interactions.

In the first place, I will mention the activities in the field of minimally invasive surgery (Stassen, et al., 1998; Cushieri and Stassen, 2000). In open surgery the surgeon opens the body by making an incision of the skin over a large area to reach the organ to be operated on. This yields a rather large open wound, however, it provides a surveyable and easy working area. Figure 1 gives a block diagram of the interaction of the surgeon and the patient.

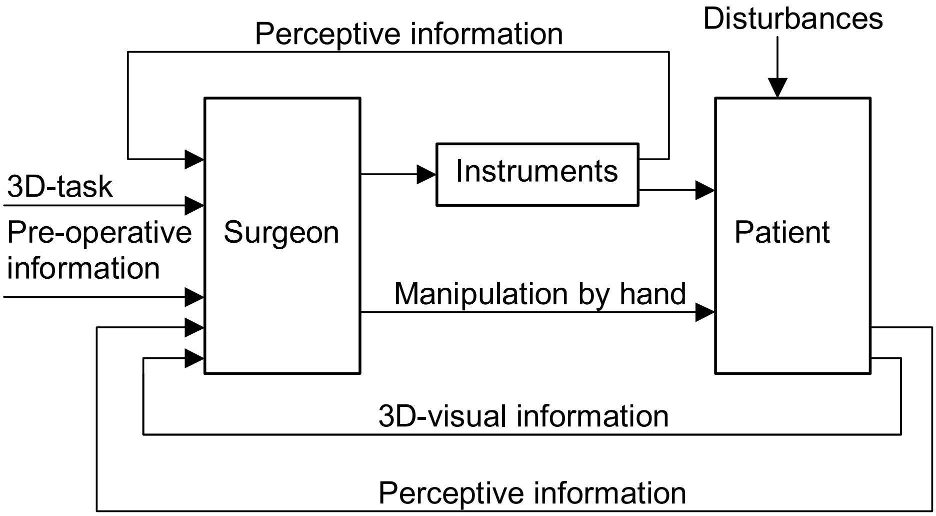
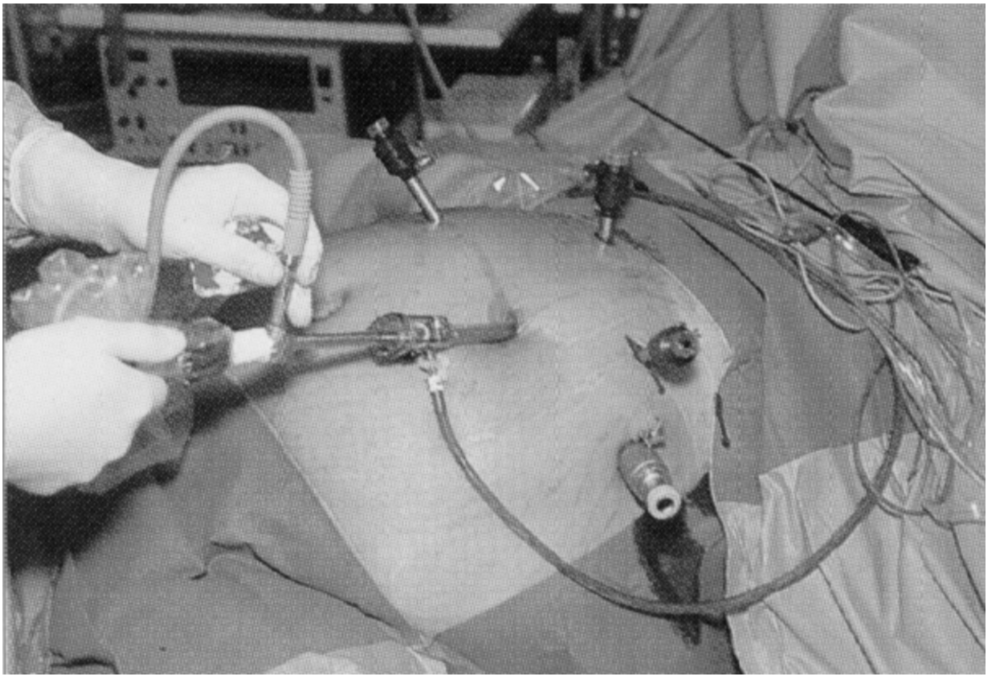



*Figure 1: Block diagram of the classical open surgery.*

In minimally invasive surgery, the surgeon injects the abdominal area with $CO_2$–gas in order to provide a surveyable working area, then he makes several very small incisions into the skin of about 15 mm. In the incisions he inserts trocars; via the trocars he is able to insert, for instance, an endoscope into the abdomen in order to provide an image of the area to be operated on, Figure 2. Via the other trocar he is able to insert instruments to perform the operation.

*Figure 2: The minimally invasive surgery set-up*



The approach is highly beneficial to the patient:

- Less damage to his / her body.
- A shorter stay in the hospital.
- Much earlier able to start working again.
- A smaller chance to get a wound infection.

However, from the viewpoint of man-machine systems interaction it demands very special skills of the surgeon. The following difficulties can be mentioned (Stassen, et.al., 1998):

- The proprioceptive feedback of the surgical instruments is degraded seriously.
- The number of degrees of freedom of the instruments used is decreased significantly.
- The visual feedback is only 2D, whereas the surgeon has to perform a 3D-task.
- The endoscope is controlled by an assistant, so the point of view is different from that of the surgeon.
- The pre-information the surgeon receives is different from the information the surgeon obtains from the endoscope due to the influence of the $CO_2$-gas injection and the gravity force. Hence, the surgeon has to translate the pre-information of CT-scans and MRI-images to the actual information he obtains from the endoscope.

*Figure 3: Block diagram of the minimally invasive surgery.*

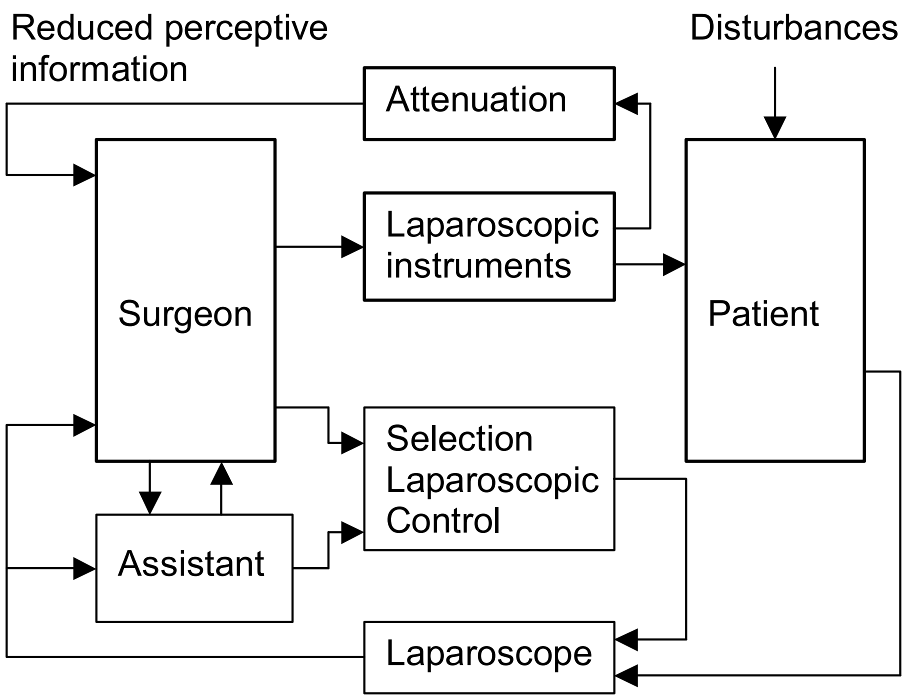


Figure 3 gives a block diagram of the minimally invasive approach. This block diagram shows the particular man–machine system difficulties. The diagram clearly shows the interesting man–machine problems.

Many other interesting man–machine problems in the field of biomedical engineering can be given. Just to mention a few, based on the experiences of my research group:

- The description of the dynamics of the control of robotic systems is of great help in the development of a three dimensional dynamic model of the upper extremities (Pronk, 1991 ; Van der Helm, 1991). Such a model is needed for the development of Computer Aided Surgery protocols in the fields of orthopaedics and rehabilitation.
- The Critical Instability Task, well–known for the measurement of mental load of operators in manual control (Jex, 1966) could be transformed into a diagnosis tool for patients with Huntington's Chorea (Schmid, 1977).
- Concepts used in developing an expert system as a Human Decision Support System for the detection and classification of alarms during the supervision of an industrial plant (Sassen, 1993) could also be used to create an expert system as a Medical Support System in the diagnosis of patients with a laesion of the plexus brachialis (Van Daalen, 1993).
- The Optimal Control Model (Baron and Kleinman, 1967) as developed to describe human manual control tasks could be used to describe the control of the shoulder muscles during goal directed movements (Happee, 1992).
- The 3D display technology as used in the control of the European robotic arm (Breedveld, 1996 ; Buiël, 1998) as well as the 4D tunnel in the sky displays (Mulder, 1999) have given a number of concepts to be used in minimally invasive surgery, in particular in brain surgery.
- The use of identification and modelling techniques in order to predict the path of Very Large Cruide Carriers, VLCC's, could be used to predict the results of the treatment of patients with a laesion of the spinal cord. It turned out that by observing the patient treated, it was possible to model the treatment process, so that the expected results of a treatment could be estimated (Stassen, et.al., 1988). This approach shortened the time needed to be in the rehabilitation center for about 15 to 20%.

The examples just mentioned illustrate that in the field of biomedical engineering many man–machine system challenges exist, and although I know that Johannsen's interest is not particularly in this area, I believe that he also will observe that many analogous problems can be found in this field of interest – the integration of engineering, multimedia and music.

Finally, another important aspect of Johannsen's professional activities should be mentioned. Johannsen was and still is a very active and invigorating member of the International Federation of Automatic Control, the IFAC. In fact, he caused the control engineers to focus at the relation between the human operator and the technical complex systems. He was the initiator of the former IFAC Technical Committee on Man–Machine Systems, TC–6, the committee that focussed the attention on the human functioning in complex technical processes. For a long time he was the chairman of TC–6 in order to provoke the control community. Johannsen was the symposium director of a series of IFAC international symposia on Analysis, Design and Evaluation of Man–Machine Systems, such as:

- The International Symposium on Monitoring Behavior and Supervisory Control in Berchtesgarden in 1976.
- The IFAC International Symposia on Analysis, Design and Evaluation of Man–Machine Systems in Baden–Baden, 1982, Varese, 1985 and Xi'an, 1989.
- The IFAC Conference on Integrated Systems Engineering in Baden–Baden in 1994.
- The coming IFAC Symposium on Analysis, Design and Evaluation of Man–Machine Systems in Kassel, 2001.

Moreover, he was the Chairman of the Sub–International Program Committee for Man–Machine Systems during the IFAC World Conferences in Budapest (1984), Tallin (1990), Sydney (1993) and San Francisco (1996).

In the USA during the period 1965–1985, the NASA University Conference on Manual Control, known as the Annual Manual, was a very popular yearly conference. It intended to review the university research sponsored by NASA that was mainly executed by PhD–students. In 1981 Johannsen supported my initiative to set up a European Annual Conference on manual and supervisory control, similar to the existing American Annual Manual. The European annual conference set–up differed from the American mainly because the European conference was not only focussed on aviation and space problems, but on a much broader field. It included manual control as well as supervisory control with applications in transport, biomedical engineering, and industrial process industry, it was called the European Annual Conference on Human Decision Making and Manual Control. Johannsen chaired the European conference three times, i.e. in 1982, 1993 and 1997.

It is difficult to compete with the powerful IEEE organisation in the USA, the IFAC is not that much appreciated in the USA. Yet, Johannsen has achieved that the IFAC is well–recognized and the Americans are still contributing to the IFAC. I hope that he will continue to put his energy in the world–wide contribution to the IFAC. In fact, Johannsen has promoted one of the major goals of IFAC, i.e. to bring the system and control engineers world wide together. He realised that the European countries and the USA had many contacts, but the relations with the Asian countries were poor. Johannsen initiated to have an extra

IFAC–symposium on the Analysis, Design and Evaluation of MMS in Xi'an in 1989. This symposium and his growing interests in the Asian culture brought him to spend half a year at the Kyoto Institute of Technology and the Kyoto University in 1995. Since that time he has spent many days building up the interaction between research in the USA, Europe and Asia.

Johannsen's research unit and the Dutch Man–Machine Systems group have many things in common, but there are also differences. Common interests are the evaluation of human–machine systems, human centred design methods, cognitive systems engineering, user interfaces, decision support systems, etc., whereas the differences are in particular the fields of application. Given these facts, I feel that I may state that Johannsen's contribution to the human machine interaction is significant. His vision on human centered design and the integration of the different disciplines is very valuable, and should be promoted extensively.

Finally, it is a pleasure to know Gunnar Johannsen, to work and to discuss research topics and the IFAC, an I hope we will continue the nice collaboration in the future.

## References


Alty, J. L.; G. Johannsen (1989). Knowledge based dialogue for dynamic systems. In: Automatica, Vol. 25, pp. 829–840.

Baron, S.; D. L. Kleinman (1967). The human as an optimal controller and information processor. In: IEEE Trans. on MMS, Vol. MMS–10, No. 1, pp. 9–17

Breedveld, P. (1996). The design of a man–machine interface for a space manipulator, 222 pp., PhD–thesis, Delft University of Technology, ISBN 90–370–0147–5

Buiël, E. F. T. (1998). Design and Evaluation of a Human–Machine Interface for a Teleoperated Manipulator, 264 pp., Delft University Press, ISBN 90–407–1687–0

CAETS (1999). Proc. of the 13$^{th}$ Convocation Technology and Health. Council of Academics of Engineering and Technical Sciences, Nice, France, 256 pp.

Cushieri, A.; H. G. Stassen (2000). Ethics in bioengineering R and D, the medical and technical viewpoint. In: Proc. of the workshop on Ethics in Technology. Delft University of Technology, In press

Daalen, C. van (1993). Validating medical knowledge based systems, 289 pp., PhD–thesis, Delft University of Technology, ISBN 90–370–0089–4

Happee, R. (1992). The control of shoulder muscles during goal directed movements, 185 pp., PhD–thesis, Delft University of Technology, ISBN 90–370–0077–0

Helm, F. C. T. van der (1991). The shoulder mechanism: A dynamic approach, 282 pp., PhD–thesis, Delft University of Technology, ISBN 90–370–0055X

Jex, H. R.; J. D. McDonnell; A. V. Phatak (1966). A Critical Tracking Task for Manual Control Research. In: IEEE Transactions, Vol. HFE 7, No. 4, pp. 138–145

Johannsen, G.; W. B. Rouse (1979). Mathematical concepts for modelling human behavior in complex man-machine systems.
In: Human Factors, Vol. 21, pp. 733–747

Johannsen, G.; J. E. Rijnsdorp; A. P. Sage (1983). Human System interface concerns in support system design. In: Automatica, Vol. 19, pp. 595–603

Johannsen G.; J. L. Alty (1991). Knowledge engineering for industrial expert systems. In: Automatica, Vol. 27, pp. 97–144

KNAW (1998). Science and Arts: A Report of a dialogue (In Dutch). Amsterdam, Royal Dutch Academy of Sciences, 8 pp., ISBN 90-6984-228-9

Mulder, M. (1999). Cybernetics of tunnel-in-the-sky displays, 416 pp., PhD-thesis, Delft University Press, ISBN 90-407-1963-2

Oohashi, T., E. Nishina (1998). Kansei science and man-machine interaction in performing art. In: Proc. 7th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design and Evaluation of Man-Machine Systems, Kyoto, Japan, pp. 1–6

Pronk, G. (1991). The shoulder girdle, 244 pp., PhD-thesis, Delft University of Technology, ISBN 90-370-0053-3

Sassen, J. M. A. (1993). Design issues of human operator support systems, 226 pp., PhD-thesis, Delft University of Technology, ISBN 90-370-0090-8

Schmid, H. (1977). Characteristics of eye movements and models suggesting brain stem organization of gaze. In: Proc. of the Int. Symposium on Control of gaze by brain stem neurons, Elsevier / North Holland Biomedical Press, Amsterdam, pp. 69–75, ISBN 0-444-80029-8

Stassen, H. G.; A. van Lunteren, R. Hoogendoorn; G. J. van der Kolk; P. Balk; G. Horsink; J. C. Schuurman (1980). A computer model as an aid in the treatment of patients with injuries of the spinal cord. In: IEEE Proc. of the Int. Conf. on Cybernetics and Society, pp. 385–390, Cambridge, Mass., ISSN 0360-8913

Stassen, H. G.; J. Dankelman; C. A. Grimbergen; D. W. Meijer (1998). Man-Machine Aspects of Minimally Invasive Surgery.
In: Proceedings 7th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design, and Evaluation of Man-Machine Systems, pp. 7–18, Kyoto, Japan

Stassen, H. G. (2000). The influence of new technology on the human-machine interaction in biomedical engineering: A challenge or a problem?
In: Proc. 7th IFAC on Automated Systems Based on Human Skill, pp. 99–108, Aachen, Germany

Stassen, H. G. (2001). Biomedical Engineering: An Interesting Multidisciplinary Human Machine Systems Field with many problems and challenges.
In: Proc. 8th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, Kassel, Germany, 10 pp.

# The GRADIENT Project and its Contribution to Man–Machine Systems Design

*James L. Alty*

Jim Alty is Professor of Computer Science, Dean of the Faculty of Science of Loughborough University, and Director of the Interactive Mechanisms for Process Control & Communications Technology Research Group (IMPACT). With Gunnar Johannsen he shares the interest in both human–machine systems and music.

## Abstract

The GRADIENT project, which was supported by the European Commission in the later half of the 1980's is described and its impact assessed. The Pilot Study is first examined and the achievements of the subsequent main project assessed. The contribution of the project to Man–Machine Systems Design is assessed.

## Introduction

In 1983, a group of Engineers and Scientists concerned with Human Interface Design and Process Control considered how the developing operator problems in the control of large scale industrial plant might be approached and solutions found. The consortium had been brought together by Jens Langeland–Knudsen of CRI International in Denmark, but it also involved Olav Holst (CRI), Peter Elzer (of Brown Boveri & Cie Aktiengesellschaft), myself from the University of Strathclyde HCI Centre (UK), Stuart Savoury of Nixdorf Computers and Gunnar Johannsen of the Man Machine Systems Group at the University of Kassel. Later, people like Erik Hollnagel (CRI) and Marcel Rijkaerts (University of Leuven) would become involved as well.

The group proposed a novel research project to the European ESPRIT programme involving Artificial Intelligence techniques and Human Computer Interaction research to develop improved interfaces for the operators of Supervisory and Control systems. In particular they planned to use expert systems techniques to provide the right information at the right time to the operator, and use intelligent graphical techniques to present the information in the most understandable manner. The approach was so novel that the ESPRIT coordinators asked the consortium to carry out a one–year feasibility study and report back. The pilot phase was labelled P600 and its main task was to develop a state of the art report to ascertain the key problems to be solved and to develop the original proposals.

The pilot study involved interviews with operators, engineers and academics over a widely differing set of application areas in a number of EU countries (Denmark, Germany and the UK). The applications studied ranged from Railway Networks, Air Traffic Control and Ship Control to Electrical Power Distribution.

## Findings of the Pilot Study

The report traced the root cause of the developing interface problem to the digital analogue controller. Such controllers contained algorithms and worked under the assumption that the process was deterministic and could be described by a complete model. All knowledge about the process and its behaviour was assumed to be built into the algorithm and human intervention was limited to changing set–points and handling emergency situations. Another, related cause was the "dumb" data–logger which had been introduced at the start of computerisation. Such devices did nothing more than log process events and store them for later evaluation.

The introduction of analogue controllers had progressively improved the performance of Supervisory and Control systems under normal conditions and had reduced the number of failures. Paradoxically, this had resulted in operators having less experience of dealing with emergencies (De Keyser, 1986), and in such situations they were thrown back onto purely manual or intuitive control.

Thirdly, with the development of the Visual Display Unit (VDU) the nature of the dialogue between the operator and system had changed, but the opportunities and problems arising from these new dialogues had not been fully appreciated. For example, the new VDUs provided the operators with very different views of the system compared with the traditional mimic board. In some aspects the new situation was better (for example the ability to display in context) but in other aspects it was problematic (the limited information that can be displayed on a VDU). The introduction of VDUs had started to raise consciousness about the "human engineering" aspects of the interface design. For example, it was about this time that the first Man–Machine Systems conference was organised through IFIP and IFAC. The concept of what constituted an "operator error" was also beginning to change. It was realised that operator errors could actually be an artefact of poor initial design.

## The Importance of a Process Knowledge Base

The report suggested that the purely deterministic view of control needed to be supplemented by knowledge of the process that the system could access when rendering information to the operator. Data and trends could be provided "in context" which would assist in the diagnosing, locating and repair of faults. The report concluded that *"there is strong evidence that the proper use of knowledge based system techniques can result in a major breakthrough"*. It was suggested that the Knowledge Based System approach would enable the building of *"causal chains and can extend the knowledge base incrementally as knowledge about the process increases ... A major breakthrough can therefore be expected in the area of fault analysis and system recovery"*.

### Improvement in VDU design

The survey criticised many current VDU devices and identified the importance of 1024x1024 colour devices rather than the 480x540 (often black–and–white) devices commonly in use at the time. The crucial importance of "flicker–free" displays was noted particularly for animation. A plea was made for large screens with higher resolution and better colour. This time was an interesting one for VDU design. Most implementations relied upon processing implemented in hardware. Although the possibility of software implementations was well known, it was difficult to obtain the required performance in software. The first high performance Unix based VDUs from SUN had just reached the market.

It is interesting to read the discussion in the report on Graphical Display. Many pointers to future developments are in there. For example, the importance of different levels of abstraction is noted, and the relative merits of "reality" versus "abstraction" are discussed. A plea is made for better iconic representations supported by intelligent graphical editors and the use of colour in reasoning processes. Out of these discussions came the requirement for an Intelligent Graphics Editor – the GRADITOR.

Operators wanted immediate response, the ability to overwrite the actions of the graphical system at will, operator customisation, good graphics and, overall, wanted to be in charge. Things have not changed.

### The Dialogue between Operators and the System

Dialogues were thought to be too inflexible and non–adaptive giving the operators the feeling that they were not in control. Dialogues were unnatural and caused sequencing problems. Often the operator knew what was to be done but was constrained by the dialogue. The importance of "undo" facilities (where possible) was highlighted.

### Possible Use of Expert System Technology in Future Systems

The report concluded with an analysis of the potential use of Expert Systems in providing operators with better support. Two key areas were identified

- The *Advisor Model* in which the operator interacts directly with the process and is provided with expert advice when required by an expert system
- The *Intelligent Front End* in which the operator interface interfaces through an expert system to the process.

The latter was thought to be problematic in that the expert system stood between the operator and system. The first area was considered to be the more productive.

One aspect that concerned the working group was the performance of existing expert systems. Whilst operators in Industrial Plant were not usually involved in split second decisions, they did have to act quickly to stabilise the system at fault, thereby enabling more detailed reasoning to take place. Given that any process model would be quite extensive, it was thought that any substantive reasoning system might take a considerable time to reach conclusions and offer advice.

The group eventually came up with an interesting idea – that of splitting the knowledge based support into two distinct systems – a Quick Response Expert System using a small knowledge base being supported by a larger (slower) system that could take a longer–term viewpoint. These rapidly became labelled QRES and SES. At the time of writing, no work had been published on such a combination of slow and fast systems.

## The Main Submission for the GRADIENT project

The P600 report was well received by the ESPRIT Directorate. The Literature Review was published and ranged over 84 pages with 210 references. The report (Alty et al, 1993) was very widely read in the process control community and often quoted at the time. As a result, the original partners (with the exception of Nixdorf) but with the addition of the Chemical Engineering Department at the University of Leuven in Belgium led by Prof. Marcel Rijkaerts, submitted the full proposal "Graphics and Knowledge Based Dialogue for Dynamic Systems" (GRADIENT for short) and it was planned to last for five years. The proposal was accepted in the summer of 1985 and called Project P857. The Technical Annex details the total cost as 14,158,000 ECUs with CRI as the lead partner. Labour took the main share of cost – 10,420,000 ECUs and the Travel Budget was 588,000 ECUs. Equipment was also expensive by modern standards, a total of 2,331,000 ECUs. It was planned to use the newly announced SUN workstations that would provide the opportunity of testing a software approach to Graphics provision.

The objectives of the project were to

- Investigate the use of knowledge based systems to support the operator of industrial supervision and control systems
- Enable the operator to conduct an intelligent graphical dialogue with the supervisory and control system, supported by a graphical expert system.

The project passed all its reviews and lasted the full five years.

## Achievements of the GRADIENT Project

What did GRADIENT achieve? It was probably the first project to fully implement a variation of the Seeheim Model (Pfaff, 1985) in Process Control. The first project to use a sophisticated form of mathematically based dialogue analysis and one of the earliest projects to use software driven VDUs in the Control Room. It also implemented a two–stage (Immediate and Longer Term) response Expert System (QRES and SES) to provide the operators with advice, and an Expert system to detect and correct operator errors (RESQ).

A particularly interesting aspect was the dialogue control system and its front end presentation system. These were fully described in a paper by Gunnar Johannsen and myself, (Alty and Johannsen, 1989), written in the third year of the project. It had a number of interesting and novel features.

a) Separation of Application, Dialogue and Presentation

b) The concept of Dialogue Assistants

c) Support for Presentation using Object Oriented approaches

d) An analysis tool which could check the consistency of dialogues

e) A sophisticated Graphics Editor.

The system was designed as a "User Interface Management System" or UIMS. All the modules could communicate and shared common knowledge.

In order to clarify the roles of each of the components the Seeheim Model is shown in Figure 1. It must be stressed that at the time the functions of some modules were not well understood, particularly the User Model. The actual control aspects of the interaction are separated out into what is called a Dialogue System.

The *Presentation System* is responsible for the actual presentation aspects of the interaction, i.e., how a particular request or interaction is carried out in the available displays and control devices. It does not concern itself with why a particular presentation technique has been chosen. The presentation system can have some "intelligence" of its own, for example it can do reasonability checks on data or define relationships between presentation objects.

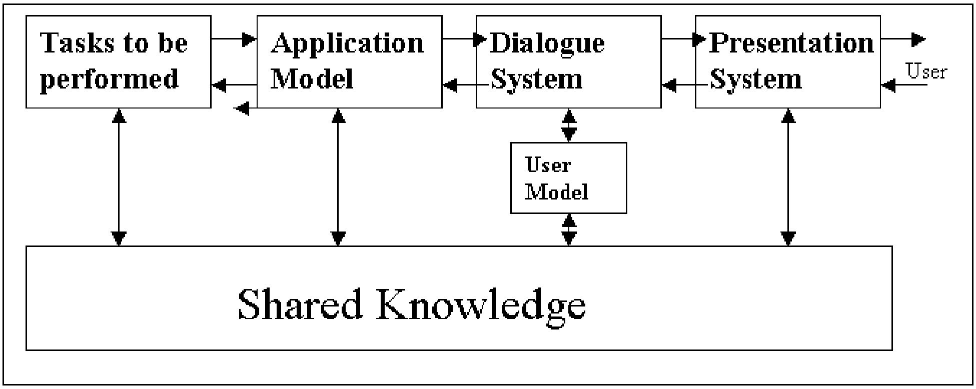



*Figure 1: Schematic View of a User Interface Management System*

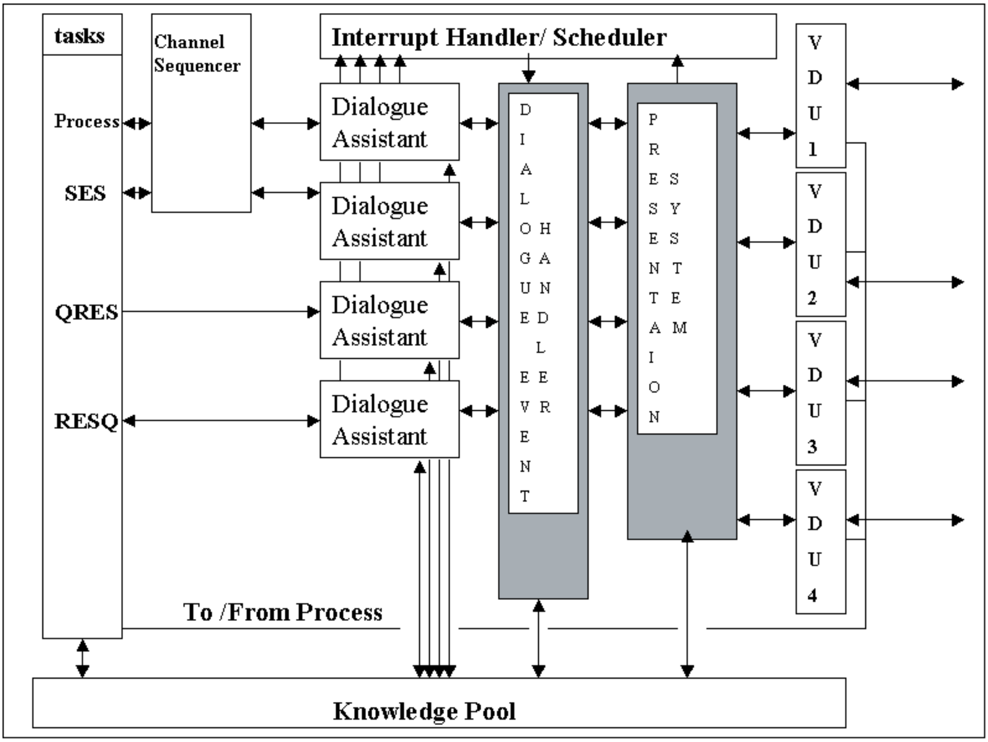
The *Application Model* is an explicit representation of the task. It involves the plans of the application, crucial data structures, current instantiations and links to actual application code. The whole of the application need not be explicit, only those parts of relevance to the user. The Application Model may well contain deeper knowledge about the process in the form of a process model.

The *User Model* (or Operator Model in the case of process control) advises the Dialogue System on which of a number of interaction styles ought to be used (e.g., icon or text, Command or Direct Manipulation) to communicate with a particular operator or category of operator, dependent upon its knowledge of the operator or category of operator in question. It might re–interpret the plans of the application in terms of operator plans. It could also be involved in tutorial interactions with the operator in times of difficulty, explaining ill–understood task aspects for which the user requires explanation. Plans in the User Model would, of course eventually map onto application plans.

The *Dialogue System* controls all the interactions between the modules. As well as being a form of telephone exchange it also contains general dialogue knowledge about the objects being manipulated, presentation styles available etc. It will normally have some application–dependent information. It has access to knowledge about users (in the User Model) and about the application (in the Application Model). Usually a Dialogue System will mainly contain shallow knowledge about procedures.

The full GRADIENT system can be seen in Figure 2 (taken from Alty and Johannsen, 1989). The separation between Presentation, Dialogue and Application Model (SES, QRES and RESQ) can be clearly seen.

*Figure 2: The GRADIENT system as a User Interface Management System*



This was probably the first attempt to implement the ideas of the Seeheim Model on a large scale (It was only four years after the Seeheim Conference). However, there was one deviation from the model that would later be adopted in revised Seeheim approaches. This is the direct connection between the operators and the process. This was done for two reasons. Firstly, for safety reasons, the operators needed direct contact with the process. It is not sensible to have many layers of software between them and the system. Secondly, because of the very large number of variables that need to be updated, they need to be routed directly to the presentation, or the system would become overloaded. This was done using Object Orientated Techniques (OOPS) that were just coming into use at that time.

There are three other interesting points to be noted from Figure 2. Firstly, the dialogue interactions are handled by a number of Dialogue Assistants. These are discrete packets of knowledge that handle individual conversations with operators on particular tasks. They have their own knowledge bases separate from other Dialogue Assistants, but can communicate through the common knowledge pool. These were also implemented using OOPS technology. We did not realise it at the time, but these are what are now termed "Software Agents" and they probably predate the invention of agents in Artificial Intelligence. The second point is that conversational knowledge in these agents was in explicit form (actually in the form of transition networks) so they were amenable to analysis. Thirdly, the diagram does not show a later development in GRADIENT – the Intelligent Graphical Expert System (GES) for advising on presentation aspects (and its related module, the intelligent Graphical Editor). These were a consequence of the need for supporting a variety of information in the presentation system (Johannsen et al, 1986).

The representation of the dialogues as explicit knowledge enabled Path Algebra Techniques (Alty and Mullin, 1989) to be used to analyse them. The dialogues were represented as transition networks. Path Algebras were defined which analysed the networks for particular properties – consistency, termination etc. Although such Dialogue Specification technique had been suggested before, and transition networks had been used to represent dialogues, this was the first really successful application of the technique. The technique worked well for network type dialogue, but the interface world was changing. At the time there was the rapid introduction of Direct Manipulation Techniques that had been suggested earlier (Shneiderman, 1982) and these were now being introduced into MacIntosh and PC computers. Such dialogues are very flat and are not amenable to network representations.

The GRADIENT project was very much concerned with Knowledge Engineering. Although such techniques were in regular use in Artificial Intelligence, they were not so well known at that time in Process Control. Indeed, there was a nervousness about the use of AI techniques in complex processes. One output from GRADIENT was a substantive review paper on Knowledge Engineering, which extended the discussion about the merits of using Artificial

Intelligence techniques into Industrial Systems (Johannsen and Alty, 1991). Another important contribution, already briefly mentioned, was the idea of separating the Knowledge based support into a Quick Response Expert System (QRES) and a "slower" more comprehensive Expert System (SES).

This arose out of worries about the likely response times of expert systems. It was thought that that reasoning time required would simply be too lengthy. The idea therefore was to have a "quick" response system which consisted of a set of production rules and which could recommend actions to stabilise the system (QRES). Once stabilised, the more comprehensive system (SES) would then be brought into play based upon deeper knowledge of the plant. The approach had some similarities with Rasmussen's Ladder Model (Rasmussen, 1984), corresponding perhaps to the Rule Based and Knowledge Based Reasoning levels. The idea proved to be very useful, and later, an additional expert system (RESQ) was added to cope with operator errors.

### The Industrial Impact of GRADIENT

It is always interesting to reflect on how the activities in research projects can influence industrial practice in the longer term. The ESPRIT directorate were naturally concerned that the funding was used not only to carry out research but also to influence industry into utilising that research. In the area of process control this is difficult because of the huge investment required in plant, the long lead times for designing and building Power Stations, and the difficulty of carrying out realistic experiments *in situ*. Although EPSRIT sought to ensure that our demonstrators were realistic, in retrospect it really is not possible to do this.

We learned from this project that research in this area can influence thinking and produce change, but the mechanism is by example and persuasion. In fact many of the ideas emerging from GRADIENT were taken up. Certainly, Asea Brown Boveri implemented some of the ideas in their next generation control rooms, and the research output when added to that of many other research centres around this time (for example Matsumura, 1989; Sakaguchi et al, 1986; Ogino et al, 1986) did have an eventual impact on industrial design. The time–scale for this however is probably 5 – 10 years.

## Conclusions

So how successful was GRADIENT? Well, the reviewers at the final project meeting in 1991 thought it had been a most successful project and we were grateful to them for their considerable and valuable input throughout the project. They were not easy reviewers, but they were fair, and constructive at all stages. Secondly it was a joint project across country boundaries in which all the participants made significant contributions. There were no passengers, only crew. Judged from its output and interesting ideas, it was successful and did influence the future path of Industrial Control Rooms. Thirdly, the ideas generated in the project were reasonably novel yet implementable. The project also gave a boost to a set of struggling research laboratories who were trying to establish themselves in the relatively new field of Man–Machine Systems. As a result, the research groups at Kassel under Gunnar Johannsen, at Strathclyde (later Loughborough) under myself and at Leuven under Marcel Rijkaerts were strengthened and the group now at Clausthal under Peter Elzer was established. Without the GRADIENT input at this time, the groups may have foundered in this crucial stage of development for Man–Machine Systems research.

## Acknowledgements

In this short paper I have concentrated upon the achievements in GRADIENT mainly arising from the areas of joint interest of Gunnar Johannsen with the Kassel group, and my own research group which was then at the University of Strathclyde, Glasgow, Scotland. I have not discussed the expert systems results in detail, not the results of the Expert Systems Metrication Project carried out by Prof. Rijkaerts and our Belgian colleagues. Clearly there were also huge contributions from people such as Erik Hollnagel, Peter Elzer, and Olav Holst as well, which have not been fully reported here. Finally, we were all grateful to the ESPRIT Directorate for funding both the Pilot Project P600 and the main project P857.

## References

Alty, J. L., and G. Johannsen (1989), Knowledge Based Dialogue for Dynamic Systems, Automatica, Vol. 25, No. 6, pp. 829–840

Alty, J. L., and J. Mullin, (1989), Dialogue Specification in the GRADIENT Dialogue System., in Proc. of HCI '89

De Keyser, V., (1986), Technical assistance to the Operator in Case of Incident: Some lines of Thought, in Hollnagel, E., G. Mancini, and D. D. Woods, (eds.), Intelligent Decision Support in Process Environments, pp. 229–253, Springer, Berlin

Johannsen, G., and J. L. Alty, (1991), Knowledge Engineering for Industrial Expert Systems, Automatica, Vol. 27, No. 1, pp. 97–114

Johannsen, G., J. E. Rijnsdorp, and H. Tamura, (1986), Matching User Needs and Technologies of Displays and Graphics, in Mancini, G., G. Johannsen, and L. Mårtensson, (Eds.), Analysis, Design, and Evaluation of Man–Machine Systems, Proc. 2nd IFAC, IFIP, IFORS, IEA Conf., pp. 51–61, Pergamon Press, Oxford

Matsumura, S., K. Kawai, A. Kamiya, T. Koi, and K. Momoeda, (1986), User Friendly Expert Systems for Turbine / Generator Vibration Diagnosis, Proc. 4th IFAC, IFIP, IFORS, IEA Conf. on Man–Machine Systems, Xi'an, China, pp. 63–68

Ogino, T., Y. Fujita, and H. Morimoto, (1986), Intelligent Man–Machine Communication System for Nuclear power Plants, in ISEA Seminar on Operating Procedures for Abnormal Conditions in Nuclear power Plants, München, Germany.

Pfaff, G. E., (ed.), (1985), User Interface Management System, Springer–Verlag, Berlin

Shneiderman, B., (1982), Direct Manipulation; A Step Beyond Programming Languages, Behaviour and Information Technology, Vol. 1, pp. 237–256

Rasmussen, J., (1982), Strategies for state Identification in Supervisory Control Tasks, and the Design of Computer Based Support Systems, in Rouse, W. B., (Ed.), Advances in Man–Machine Systems Research, Vol. 1, JAI Press, Greenwich CN, pp. 139–193

Sakaguchi, T., R. Fujiwara, H. Suzuki, and Y. Kohno, (1986), Design and Development of Human Interface in Engineering workstation for power Systems planning, in G. Mancini, G. Johannsen, and L. Mårtensson, (eds.), Analysis, Design, and Evaluation of Man–Machine Systems (Proc. 2nd IFAC, IFIP, IFORS, IEA Conf. ), pp. 1–9, Pergamon Press, Oxford

# 15 Years Research and Experiments in Aeronautics in the Laboratory for Human–Machine Systems

*Bernd–Burkhard Borys*

## VAX and MEGATEK: The Error–Tolerant Control Input System

### Hardware

When I joined Gunnar Johannsen in 1984, we belonged to the network pioneers in the University, building in cooperation with three other groups from mechanical and civil engineering the "Process Computer Network B", based on Digital Equipment hardware and yellow–cable Ethernet. We operated a DEC VAX 751 with 1 MByte of memory, one 134 MByte disk, and four ASCII terminals. The VAX was equipped with a MEGATEK 7255 graphics system, drawing vectors in four (out of 16) colours on a 1024 by 1024, 19" pixel display. At that time we paid for the initial version of the VAX 166000 € and another 118000 € for the MEGATEK system. With support from different sources, we extended the system to 4 MByte of memory, a floating–point accelerator unit, 16 colours and a multi–channel analogue–digital converter. The system was the core of the first flight simulator, used to evaluate the *Error–Tolerant Control Input System* (FTBS: Fehlertolerantes Bediensystem, Heßler 1989).

Bernd–Burkhard Borys joined Gunnar Johannsen and the Laboratory for Human–Machine Systems as Senior Scientist in 1984. He assisted building up the laboratory, in particular the technical, computer and network infrastructure. He worked in and / or managed several projects, among these GRADIENT, FANSTIC, and FANSTIC II. His current research interest are auditory displays, in particular 3–D sound to support aircraft and vehicle control.

*Figure 1: Vax 751*

The idea of the FTBS was the following: Aircraft automation can handle complete flight phases automatically. If, however, the pilot decides to fly manually, the automation can be used to detect pilot errors. The Deutsche Forschungsgemeinschaft supported this project from 1985 to 1990.

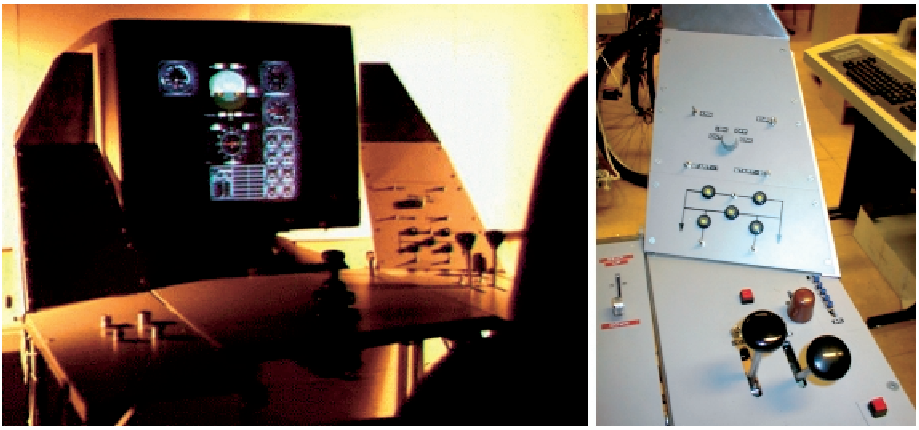


*Figure 2: FTBS Cockpit and Controls*

For the evaluation, Heßler build a fixed–base flight simulator with sufficient hardware to operate flight controls, flaps and gears, radio navigation equipment, and engines. Hardware controls were mechanically linked to variable resistors that provided input signals for the analogue–digital converters. On the computer side, a FORTRAN coded model of a small business jet aircraft (HFB 320 Hansajet) computed flight path, system state, and IFR instrument readings. The simulator hardware and the pilot's seat were mounted on a small cart that was positioned in front of the MEGATEK terminal displaying the instruments and the FTBS messages.

## Experiments

Professional airline pilots performed a navigation scenario in the experiments with several repetitions, covering one complete day for each pilot. The scenario started with level flight at 210 KT in 3000 ft GND followed by an approximately four minutes holding. The pilot than received radar vectors to the localizer intercept while he had to keep the assigned altitude and to reduce speed to 180 KT until receiving the ILS approach clearance. The final approach ended with either landing or go–around. The FTBS controlled flight path, speed, and operation of gear and flaps.

The experiments should give answers to three questions: (1) Is the FTBS useful? (2) Is it accepted? (3) How does it influence workload? These were the dependent variables that were expected to depend from the factors (a) type of presentation, (b) workload induced by flying task, and (c) degree of automation. Factor (a) covered a conventional cockpit vs.

textual vs. graphical FTBS messages and factor (b) was varied by introducing one or two technical problems. Factor (c) was either manual or automatic.

Subjectively experienced workload was measured online by verbal questions and answers during the experiment and offline with a questionnaire afterwards. Relating FTBS messages to pilot actions produced a classification of events as *positive* (action follows message), *negative* (action before message issued), and *simultaneous*. Results showed that the FTBS presented the right messages at the correct times and that pilots responded faster to information from the graphical interface than to text messages. Heßler (1989, 1992) and Heßler and Ridlhammer (1991) report the results in detail.

## Sun and Linux: Experiments in Peripheral Vision

### Hardware

VAX and MEGATEK were the main computer system for nearly ten years. With support from the European Union during the project GRADIENT (described by Jim Alty earlier in this book) a MicroVAX and two Symbolics LISP machines extended the equipment, and we entered the UNIX world, starting with a SUN IV in 1988. Finally in 1993 we moved completely to UNIX when receiving a grant of 105.000 € from the University and the Federal Government in the *Scientists' Workplace Programme* (Wissenschaftler–Arbeitsplatz–Programm WAP) that provided us with a Cluster of five Sun SPARC workstations and an Evans + Sutherland graphics accelerator. The experiments for evaluation of new displays optimised for peripheral vision used this equipment as well as software for prototyping avionics equipment purchased with support from the *FANSTIC* project.

The need for peripheral displays in helicopters arises from the fact that a helicopter pilot has to focus to the outside world while still regarding the interior instruments. Typical helicopter mission considered were landing at a accident site between obstacles in an urban environment in a rescue mission or flying close to trees for calcification of forests to prevent problems of acid rain. While foveal vision is necessary to react on the outside threads, helicopter instruments are perceived only in the visual periphery, 30 to 60 degrees to the left. To evaluate the benefit from the instruments Jörg Hartz (1993, 1995, 1997) created, he build simulation environment around a helicopter mock–up.

*Figure 3: Helicopter Cockpit*

Figure 4: Canyon View

## Experiments

This was the first distributed simulation environment and the first time, that elements from computer games software were used in our lab. A LINUX PC provided the helicopter simulation and freeware add–ons for the game DOOM created and displayed outside vision: A narrow valley winding its way between vertical mountains. Using a LCD display and an extra–bright overhead slide projector, the image was thrown on the wall in front of the helicopter cabin. Commands from the helicopter controls (two–axis stick, pedals, collective, and a trigger button) were received by an analogue / digital converter of a Sun SPARCstation 10. The Sun sent controls information to the PC, controlled the experiment, logged the data, and generated the peripheral instruments graphics. The first independent variable was the type of display: one conventional (dial–und–pointer) display, and four new displays, among these open shapes like an >H<, and closed shapes like a hexagon or octagon. Events were indicated by motion of the pointer, an arm of the open or a corner of closed shape. The distance of the peripheral display was the second independent variable: An additional computer screen was mounted 30, 45, or 60 degrees off to the left. The last independent variable was the distinction between "movement starts" and "amplitude increases" to signal an event.

Helicopter pilots from *Bundesgrenzschutz* (the German boarder patrol and federal police) with experience in ambulance flights were included in the 30 hours of experiments. The scenario was a SAR mission: Fly as fast as possible through the valley to reach the victim at the end and confirm changes on the peripheral display by pressing the trigger button. This narrow design of the valley forced the pilots to look on the outside display, which was verified with an eye–tracking camera before the experiments; the camera turned out to be too heavy for use throughout the experiments.

Dependent variables were the time to react, number of missed events, time to complete mission (including penalty for leaving the centre of the canyon), and reported difficulty to detect events (on a 10–point scale). Results, as reported in detail in the PhD thesis of Hartz (1997), showed the superiority of the new displays over conventional instruments.

We used the UNIX workstations until the end of the 90's, finally as file–, web–, and e–mail–servers while PCs became standard for scientific work.

## PCs and Visual Basic: The Multi–Attribute Task Battery

### Project FANSTIC

From the years 1990 to 95, the Laboratory for Human–Machine Systems participated in *FANSTIC* and *FANSTIC II*. Europe's leading aeronautics companies worked together in this project to increase air traffic safety. We conducted task analyses in the beginning of the project and later were main responsible for coordinating the subtask on the Implications of future *Air Traffic Management* on the work in the cockpit and on the ground. Research showed that future technology would result in improved information exchange between participants in air traffic and that a new as well as a more flexible distribution of functions between air and ground as well as between man and machine would be reasonable. However, human controllers and human pilots will remain the key elements in the system and the final responsibility will remain with the pilot (Borys 1997).

In these years, several incidents and some accidents in air traffic were related to inadequate function allocation to the pilot. In the need not to overload the remaining two pilots in modern glass cockpits, aircraft automation took over ever more functions. As a result, in several known cases pilots lost the necessary close contact to the aircraft, were surprised by automation, unaware of system states, overlooked hidden functions, or lost track of developing situations. It was also feared that continuous increase of automation would result in a dangerous loss of familiarity of pilots with the basics of aviation. Consequently, one key to increased safety was not to reduce pilots' workload by increasing automation but to find an optimal distribution of functions between man and machine.

A promising vehicle for evaluating the influence of different function allocation was the *Multi–Attribute Task Battery* (MATB) used by Parasuraman (Hillburn 1993).

### Hardware

During the years of *FANSTIC*, our hardware environment changed from the few UNIX workstations to a network of Windows 3.1–PCs. Using Visual Basic and TCP/IP, we implemented a MATB by combining four interconnected PCs – one for controlling the experiment and three driving three independent screens showing five windows with five independent tasks. The screens were arranged consistent with glass cockpit environments together with input devices.


*Figure 5: MATB Mockup*

## Experiments

To find out how combination of functions assigned to the human influences performance, we implemented the MATB with five different tasks approaching typical work in an aircraft cockpit: A compensatory tracking task (manual control (C)), stepwise selection of way points (navigation (N)), a fuel tank selection and pump switching task (system management (M)), instrument monitoring (I), and simple arithmetic calculations (A).

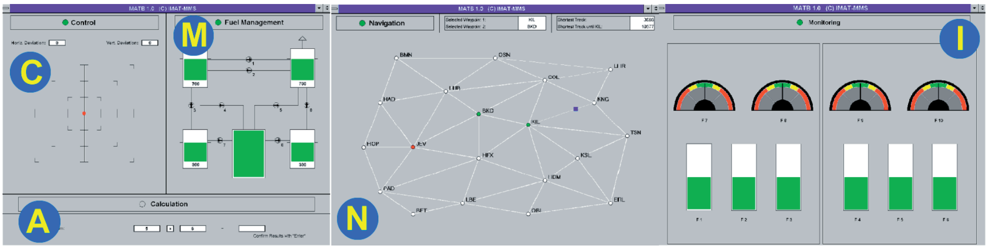



*Figure 6: MATB Screens*

Two experimental series involved eleven pilots and five students of mechanical engineering. Three pilots held commercial licenses, the others licenses for single-engine planes, some with additional IFR or instructor ratings. We had discussions with our partners from aircraft industry about the validity of an experiment with non-commercial pilots and without using a certified flight simulator. We can take the group of students as a control group: Indeed, students showed different performance on the tasks. Mainly in the manual control task, tracking error (RMS of deviation) was much lower for the students on the cost of higher joystick activity (RMS of deflection – influence of video games?). In addition, the measure for scanning irregularity (described below) was significantly lower for pilots. However, we were not interested in absolute values of performance, but in changes of performance and behaviour on variation of function allocation. Thus, using a Z–transformation we normalized the measures taken for each subject into a score of zero mean and unit standard deviation, using this score for calculating differences for the experimental set–ups.

Interested in workload, besides a questionnaire, we used the calculation task as a secondary task and took two measures. The first was the inverse of the workload indicated by the number of calculations performed during one experiment. A larger number of calculations suggested more spare capacity unoccupied by the other tasks. The second was a measure of scanning irregularity versus periodicity. We calculated the time differences between two consecutive calculations and the standard deviation of these differences. Small standard deviation means similar time differences and work that is more regular. The idea behind this was that work in an aircraft cockpit should follow a regular scanning pattern, performing one task after the other in regular intervals.

The number of correct calculations was no useful measure, as nearly all results were correct and no error was made in half of the experiments. Using the scores of workload and scanning regularity the experiment showed, that workload when performing two tasks in parallel cannot be estimated from single–task measurements. Taking the calculation score as an objective workload measure, it indicated maximum workload (lowest score) for the management task, while the other three (navigation, monitoring, and control) showed lower workload when performed as a single task.

Bringing together two of these low–workload tasks also results in a low–workload two–task combination. But combining the management task with other tasks showed existing mutually dependency of tasks: Although navigation as a single task produced the lowest workload it is not the optimum choice when adding a second task to the management task. An evaluation of the scanning irregularity shows analogous results; those combinations showing good results with respect to workload also show regular scanning patterns. For a transition from the two– to the three–task–situation comparable results could be expected. More details are included in Tiemann and Borys (1995) and Borys (2000).

## Multimedia and DirectX: Auditory Support for Pilots

### Hardware

Since 1999, the Laboratory for Human–Machine Systems evaluates the use of auditory displays to convey information in human–machine interaction. The equipment used is part of the *Multi–Media Process Control Room* described by Borys and Johannsen (1997), made possible by grants from the State, the University and several industrial companies totalling 166 000 €.

The core of the auditory workstation is a Pentium II, 350 MHz PC with 128 MB memory, running *Microsoft's Windows 95*. Besides ordinary computer peripherals (mouse, alphanumerical keyboard, monitor), this workstation is equipped with a piano keyboard and microphones for input as well as speakers, headphones, and a synthesiser for output. Piano keyboard and synthesiser are connected by a MIDI multiplexer with each other and to the computer. Regarding the signals we use we need to distinguish between *music* and *sound*. Musical signals are generated by the piano keyboard, processed by the sequencing software, and reproduced by the synthesiser; Johannsen (e.g., 1999, 2000) described the experiments with musical signals. My focus, however, are sound signals.

For sound signals, stored as a series of digital numbers, several different media players exist, but none of them gives the necessary control over sound playback necessary in experiments. However, sophisticated sound is essential in modern computer games. *Microsoft* supports using computer games on *Windows* by providing *DirectX* as an interface between gaming software and the operating system and the *DirectX Software Development Kit* for game developers. Components of DirectX are *DirectSound*, providing necessary means of playing sound samples and *DirectPlay* for network games. A typical processing sequence for an acoustical display is: Selecting a sound according to the measurement to be displayed, reading this sound from a wave file into a sound buffer, manipulating the sound according to the measurement to be presented, and playing the sound buffer. Using *DirectSound* routines and *Borland's* C++ development environment, we developed a set of object–oriented routines to generate, store, read, and manipulate sound signals. Other routines allow adjusting sound level, panning stereo signals, fade in and out, and finally play the sound, providing all necessary means to control pre–recorded or synthetic sound during experiments.

## First Experiments

We currently work on several experiments using auditory displays (Borys, 2001). The first dealt with perception of office sounds, the next used auditory cues in a tracking task. Finally under development is an environment for evaluating auditory cues in an aeronautical environment.

When purchasing software products, these are often accompanied by collections of sounds that are triggered by events like programme failures, informative messages, or just an audible click for each mouse click. What does the user feel when hearing a single, isolated sound? Does it give a clue for the event the software developer thought it should be connected with?

We used a set of about 50 sound files provided with *Microsoft Office 97 for Windows*. Sounds were played in random order and the subjects hat to rate each sound in four dimensions, each on a 7–point–scale. The dimensions were (originally in German)

(1) *annoying ./. comfortable*, (2) *alerting ./. calming*, (3) *a failure ./. a success*, and (4) *a beginning ./. an end*. Results show a strong correlation between the first three judgements. Thus, we combined these for a distinction between nice and ugly sounds. Sorting out those sounds were subjects cannot decide and those, were decisions did not agree leaves two small set of *nicest* and *ugliest* sounds. The nice sounds seem to be soft, structured, and of high quality (e.g., 16 Bit, 22 kHz), while the ugly sounds are loud, simple, and low quality (e.g., Windows 3.1 standard). We tried to correlate the subjective decisions with technical measurements like power, overall spectrum, or frequency distribution over time. Only the power measurement (root–mean–square of signal samples) distinguished between *nice* (low RMS power) and *ugly* (high RMS power value) sounds.

The second experiment used four different displays and a two dimensional compensatory tracking task. In display version A (standard visual), the target was visible on the screen and the subject had to compensate deviations from the screen centre using a joystick. In the other versions, the target itself was no longer visible. Instead, a signal showing the direction of the deviation is triggered when the deviation is above a fixed threshold. Display Version B (threshold visual) uses large arrows visible on the screen. Version C (threshold auditory) uses voice output commands (*left, right, up, down*) and version D (continuous auditory) uses the same sounds, but increases sound power with larger deviations.

Results showed significant lower performance of the versions B to D compared to A. They also showed, that signalling amount of deviation using sound power does not increase performance.

The low performance of acoustic displays over visual displays can be attributed to two facts: Firstly, the visual stimulus is continuously available while the spoken word, although short (520 ... 720 msec), needs some time to be completed until it can be repeated. Secondly, the spoken command must be perceived, understood, and translated into the necessary manual action, while the relation between deviation of a cursor and the required action on the control is more direct. This reminds of the *Picture Superiority Effect* mentioned by Wittenberg in another chapter of this book. Consequently, in further experiments we will evaluate directional acoustical cues to signal deviations in a process control environment and to signal threads in and aeronautical scenario.

## Planned Experimental Set–Up

Acoustical signals in current aircraft cockpits do not provide spatial information. Pilots, however, need to know about the own aircraft's position in relation to the given flight path, navigation fixes, and other aircraft. Currently we prepare for investigation of directional sound use during ILS approaches and for TCAS warnings. The mock–up uses the helicopter cabin mentioned in Section 2, several networked PCs, Microsoft's Flight Simulator, and own software that makes use of *DirectPlay* to track the flight simulator. The PC running the flight simulator provides two video signals, one connected to a video beamer providing outside vision in flight direction, the other sent to a digital flat panel display showing the instruments.

## Conclusion

The Laboratory for Human–Machine Systems, created by Gunnar Johannsen, now exists for nearly 20 years. We have seen great changes in technology during this time. In three generations our equipment developed from one single computer over few workstations to multiple PCs, while the interfaces improved from text and simple graphics to multi–screen, multi–window, and multimedia systems. The technological development faces the human with an ever more complex environment. Fewer people need to control larger systems on more abstract levels. We still hope, that new capabilities of interfaces enable us compensate for inflating demands on the human operator. Our research goals remain the same: Providing the interfaces that keep the human in the loop and provide the means to master the demands of technology.

## References


Borys, B.–B. (2001): Hardware, Software, and Experiments for Auditory Displays. In: Morton Lind (Ed.): Human Decision Making and Manual Control (Proceedings of the 20th European Annual Conference on ...), Kongens Lyngby, Denmark, 25 to 27 June 2001

Borys, B.–B. (2000): Function Distribution between Man and Machine. In: P. Elzer; R. H. Kluwe; B. Boussoffara (Eds.): Human Error and System Design and Management (Lecture Notes in Control and Information Sciences, 253; edited by M. Thoma), pp. 211–215. London: Springer, ISBN 1–85233–234–4

Borys, B.–B. (Ed.) (1997): Recommendations for a Human–Centered Air Traffic Management System. Synthesis Report UKS–2.3–SR 001; BRITE–EuRAM Project FANSTIC II.

Borys, B.–B.; G. Johannsen (1997): An Experimental Multimedia Process Control Room. Advances in Multimedia and Simulation (Proceedings of the 1997 Annual Conference of the Human Factors and Ergonomics Society Europe Chapter Annual Conference, Bochum 1997) ISBN 3–00–002435–2

Hartz, J.–O. (1993): Designing Displays for Using the Full Visual Field. In: G. Johannsen; B.–B. Borys (Eds.): Proceedings of the 12th Europeam Annual Conference on Human Decision Making and Manual Control, pp. 51–55. Kassel: IMAT, Universität Kassel

Hartz, J.-O. (1995): The Integration of Peripheral Vision Supporting Features into Conventional Display Design. Proceedings of the 8th International Symposium on Aviation Psychology, Vol. 2, pp. 863–868. Columbus, OH: Aviation Psychology Lab

Hartz, J.-O. (1997): Darstellung von Flugparametern in der visuellen Peripherie am Beispiel der Entwicklung von Hubschraubercockpits <Display of Flight Parameters in the Peripheral Visual Field>. PhD Dissertation; Universität Kassel

Heßler, C. (1989): Einsatz eines Aufgabenmodells zur automatischen Erkennung von Bedienfehlern in der Flugführung <Implementation of a Task Model for Automatic Detection of Pilot Errors in Flight Control>. Automatisierungstechnik, 37 (1989), pp. 355–362

Heßler, C. (1992): Online-Simulation, ein Hilfsmittel zum Führen langsamer Prozesse <On-Line Simulation, an Aid to Support Manual Control of Slow Processes>. PhD Dissertation. IMAT-Bericht MMS-13; ISSN 0940-094X

Heßler, C.; R. Ridlhammer (1991): Entwicklung und experimentelle Bewertung eines fehlertoleranten Bediensystems für die Flugführung <Development and Experimental Evaluation of a Failure-Tolerant Manual Control System for Flight Control>. Reprint of the Final Project Report, DFG-Project Jo 139/2-2 "FT-Bediensystem". Kassel: IMAT-Bericht MMS-12; ISSN 0940-094X

Hilburn, B. G. (1993) The Effect of Long- versus Short-Cycle Schedule on Performance with an Adaptively Automated System. Catholic University of America

Johannsen, G. (1999): Design and understandability of digital-audio musical symbols for intent and state communication from service robots to humans. In: Proc. 2nd COST-G6 Workshop on Digital Audio Effects (DAFx99), Trondheim, Norway, Dec. 9–11, 1999, pp. 171–174

Johannsen, G. (2000): Auditory displays in human-machine interfaces of mobile robots for non-speech communication with humans. In: I. Troch, F. Breitenecker (Eds.): Proc. 3rd MATHMOD, IMACS Symposium on Mathematical Modelling, Vienna, Austria, Febr. 2–4, 2000, Vol. 1, pp. 47–50

Tiemann, M.; B.-B. Borys (1995): Verringerung der Belastung von Piloten durch veränderte Aufgabenteilung zwischen Mensch und Maschine <Reducing Pilots' workload through Changed Function Distribution between Human and Machine>. In: H.-P. Willlumeit, H. Kolrep (Eds.): Verläßlichkeit von Mensch-Maschine-Systemen <Reliability of Man-Machine Systems>, pp. 139–153. Berlin, Technische Universität, ISBN 3-7983-1650-3

# Mental Workload, Mental Models, and Supervisory Control

*Neville Moray*


## Abstract.

Twenty five years ago Sheridan and Johannsen (1976) introduced the concept of supervisory control. Since then the rise of automation has made the concept even more important, and has emphasised the need to understand how humans adapt to their role in such systems. In this paper two important issues are briefly examined, the nature of operator mental workload in supervisory control and the nature and role of operator mental models.


## Supervisory control

This **festschrift** is in honour of one of the founders of the field of Supervisory Control. Indeed the NATO meeting organised by Gunnar Johannsen and Tom Sheridan in 1976 marks the public emergence of the discipline, and the launching of the term (Sheridan and Johannsen, 1976). It is a pleasure to have the opportunity here to acknowledge the debt owe to Gunnar's work in the field over many years.

The chief characteristics of Supervisory Control have been well summarised by Sheridan in a number of papers and books (1992, 1997). As a result of automation, (the replacement by a machine of the role of a human operator,) the prevalence of manual control has decreased. Under normal operating conditions little intervention is required for periods which may last for many hours. Intervention may from time to time be required to assist the automation in dealing with perturbations beyond that foreseen during system design, or to take advantages of "windows of opportunity" to improve performance beyond the bounds of long horizon optimisation (Seiler, 1994). Sustained intervention is often required during the start–up and shut–down of a complex industrial plant, and intervention may be required to reprogram automation in just–in–time response modes.

Sheridan (1997) has suggested that the human operator has five roles to play, teaching (that is, programming and adjusting the automation), learning (understanding how the system works, discovering constraint boundaries for operation, forming a mental model of the system), monitoring (keeping track of the system state from moment to moment), intervening (taking back control if the automation is unable to cope), and planning (setting long term goals and defining ways to achieve them). Of these, it would seem that monitoring is the only task that must be performed more or less continuously, and may be the major source of continuous mental workload. Monitoring also supports, but does not guarantee, learning, and learning itself will be source of load, since it typically involves "knowledge based" thought on the way to building up a set of rules that will support more common and

Neville Moray, MA. D.Phil., FHFES, FES, CHFP, DERA Professor of Applied Cognitive Psychology, Department of Psychology, University of Surrey
"Be well, do good work, and keep in touch." (Garrison Keillor)

less demanding "rule based" thinking and operation (Rasmussen, 1986; Rasmussen et al., 1995).

## Workload in Supervisory Control

The period of the most concentrated research into the nature and measurement of mental workload was the two decades between about 1975 and 1995. While there was considerable effort made to develop theory, the most important outcome was the development of several practical and validated measures which seem to relate reasonably well to aspects of behaviour and performance such as performance efficiency and the probability of errors. The two best validated subjective measures were the NASA TLX scale (Hart and Staveland, 1988) and the SWAT scale (Reid and Nygren, 1988). Both are multi-dimensional, and measurements using them correlate well. Table 1 shows the TLX dimensions.

*Table 1. The dimensions of the NASA-TLX scale for measuring subjective mental workload*

- Mental demand
- Physical demand
- Satisfaction with own performance
- Time pressure
- Frustration level
- Mental effort

The many behavioural measures such as dual task techniques are far harder to use than is generally accepted, and have often been used without due regard of the warnings given many years ago by Sanders (1979) and others (e.g. Wierwille, 1983). Because of the low bandwidth of most industrial supervisory control tasks and the high degree of automation, it is not likely that dual task methods will be useful.

Apart from the rarity of practical techniques for predicting mental workload which have emerged from the period of intensive research, three other characteristics stand out. First, very little work was done in the setting of very large industrial plant involving automation. Second, there was little systematic theory generated to account for the origins of mental workload. Thirdly, little attention has been paid to underload as a source of mental workload. Mental workload usually increases when attention must be switched rapidly between sources of information, and when decisions must be made rapidly. Also, when information must be processed rapidly, perceived load tends to increase, although only occasionally have quantitative measures such as Information Theory been successful as a metric. We are thus left with a rather weak basis on which to examine how the nature of supervisory control will generate workload problems.

The relation of Sheridan's tasks to the subscales of the NASA TLX scale is not immediately obvious. Physical demand tends to be slight, being mainly concerned with entering commands at a computer keyboard, touch–screen, or by manipulating a mouse or trackball. Under normal operating conditions time pressure should be slight, since the bandwidth of automated systems, as perceived through the human–machine interface, will usually be low. Frustration level should be low if the system is well designed, although opinions differ. For example, it is common for people in the US nuclear industry to suggest that a highly automated NPP would be boring ands frustrating for the operating crews, although conversations with Canadian NPP operators does not reveal any such feeling, although CANDU reactors are far more automated than are those in the USA. (Probably this reveals the importance of cultural differences in NPP operation.) With a well designed interface, estimating the system state and understanding its implication should neither be highly demanding nor require much effort. Thus overall one might expect supervisory control to be inherently a situation of low mental workload.

On the other hand, workload must greatly increase during failures of automation, that is in situations where the normal parameters of system performance are extensively violated. But supervisory control can occur in many different systems which imply a variety of kinds of workload, and it is useful to consider how workload may change as a function of the type of automated system encountered.

Figure 1 is based on a classical taxonomy of automation proposed many years ago by Sheridan and Verplanck (1978) and recently elaborated by Parasuraman, Sheridan and Wickens (2000). The figure shows the interaction between operator and automation at several of the levels of automation proposed by Sheridan and Verplanck, from fully manual control to fully autonomous automation. The right hand column shows the flow of information and control between the human and automation. Several levels have been omitted from the original figure.

It is clear that at the highest and lowest level there is considerable computational load for the single operator, be it human or automation. At intermediate levels we might expect the load on the human operator to be progressively reduced by advice as intelligent control is passed progressively to the automation,. But while the mental load involved in decisions and control actions is reduced, a new source of mental workload appears, namely the communication load as information passes between the operator and the automation.

| Level of Human-Machine interaction | Human Functions | | Machine Functions |
|---|---|---|---|
| 1. Whole task done by human except for actual operation by machine | DETERMINE possible actions<br>SELECT action<br>INITIATE action | -----------> | PERFORM action |
| 2. Computer displays best option | ANALYSE proposals<br>SELECT action<br>(perhaps a different one)<br>INITIATE action | <------------<br><------------<br>-----------> | IDENTIFY possible actions<br>DISPLAY options<br>PROPOSE an action<br>PERFORM action |
| 3. Computer chooses an action and performs it if human approves | ANALYSE proposals<br>APPROVE action | <-----------<br>-----------> | IDENTIFY possible actions<br>PROPOSE action<br>PERFORM action |
| 4. Computer chooses an action and performs it unless human disapproves | (DISAPPROVE action) | <-----------<br>-----------> | IDENTIFY possible actions<br>PROPOSE action<br>PERFORM action |
| 5. Computer does everything autonomously | | | IDENTIFY possible actions<br>SELECT action<br>INITIATE action |

*Figure 1: The Sheridan–Verplanck Taxonomy of human–machine interaction. Actions in parentheses indicate implicite or optional steps.*

To consider advice and decide whether to accept it is itself a task involving complex cognitive activity. Indeed Conant (1976) has shown that filtering information (in this case deciding whether to act on advice) requires as much information to be processed as transmitting information. There may well be no nett reduction in mental workload at intermediate levels of artificial decision aids. In some situations the mental workload on the operator will indeed be reduced – above all at Levels 3 and 5 of Figure 1. At Level 3 the operator normally does whatever the automation suggests, and at Level 5 the operator's task is even less, just to monitor the decisions made by the automation, in case intervention is needed. *Providing that the automation is reliable* Level 5 should provide the minimal operator workload.

In order to estimate the reliability of the automated advice the operator needs a deep understanding of the system and an up to date estimate of system state. If the system is perceived as reliable, the operator's trust in the system will increase, and this will cause monitoring to decrease (Muir and Moray, 1996), giving rise in the limit to what has been called *complacency*, or a tendency to over–rely on automation (Parasuraman and Riley, 1997; but see also Moray and Inagaki, 2001(a)). To ensure appropriate calibration of trust the process must be monitored frequently, and the relation between system state and proposed actions analysed. If operator trust in reliable automation is well calibrated, then time pressure in the NASA TLX sense will tend to be low, as will effort. Physical load will be low, frustration will be low unless boredom occurs (and as we have seen this may depend on the culture rather than on the task itself), and indeed workload on all the scales will drop.

The main steady state source of load will be monitoring. There will, in a large system, be many variables to monitor, and because of the limited rate at which attention can be directed to multiple sources, it will be very hard to keep an up to date estimate of the system state. This is largely independent of the type of control room. In a large conventional control room eye movements or body movements are required to allow the operator to scan the many instruments. In a computerised system it will be necessary to switch between many pages of computer displays. In such tasks humans are well approximated as single channel monitors, and several general models are available to predict monitoring behaviour (see, e.g. Moray and Inagaki, 2001(b)). As operators gain experience of the dynamics of a system monitoring will tend to become automatic and skill–based, and will tend to approach an optimal strategy if one exists, with a progressive reduction of workload.

Very little research has been done on workload under different levels and styles of automation. Moreover, the situation changes dramatically when faults occur in the automation or in the controlled process. There may be drastic changes in the bandwidth of the system, requiring changes in the frequency of monitoring. The transfer functions of parts of system may change, and some functions may no longer be. At such times operator behaviour will tend to be driven back to knowledge based reasoning, with the concomitant increase in work load.

A special problem is what has been called *clumsy automation*, which has been identified particularly in aviation (Wiener and Curry, 1980). In clumsy automation the actions required to interact with the automation are very demanding on the operator. Since such reprogramming is most likely to be required under abnormal or rapidly changing situations, the automation becomes a source of increased workload just at the point where operators would hope it to be reduced. In advanced civil aircraft pilots frequently complain that the automation is most effective in *en route* control, where there is little load on the pilot anyway, while during approach and landing the extra load of programming the automation increases the load to such an extent that they may try to inactivate it. The pilot of one of the Airbus series of aircraft told the author that it was a wonderful aircraft to fly, but only very experienced pilots should be allowed to fly it because it was so difficult to understand the automation – surely the ultimate "irony of automation" (Bainbridge, 1983).

## Mental Models

Because of the limitations on the rate at which variables can be sampled, and the limitations of running memory, it is obvious shown that no operator with conventional displays can keep track of the state vector of a high dimensional dynamic system. It is often said that what enables operators to handle large and complex automated systems is their possession of a *mental model* of the system, and that they use this model as a substitute for direct knowledge of system state.

Although the notion of a mental model is attractive there have been few attempts to analyse formally what such a model could be. Indeed the literature is extremely confused, and it is often unclear whether to say someone has a mental model is to say anything more than that they know what to do in various situations (Wilson, and Rutherford, 1989); and the different research paradigms which examine the concept of mental models have little in common. Recently Moray (1997, 1999) has attempted to show the relation among the various meanings of the term, and has tried to show how the idea of a mental model might be formalised.

In supervisory control we have to think of the operator through training and experience as constructing a series of mappings from the properties of the system into his mind. The most important mapping represents perceived causal relations among the system variables. A mapping is the construction of a many–to–one representation in the mind of the causal properties of the supervised system. Once such a representation has been built, the causal redundancy in the physical system becomes represented in the mind as a series of correlations, many of them extremely strong. Hence a subset of variables is sufficient during monitoring for a sufficient estimate of those that are unobserved. This accounts for the reduced workload of the expert, and of the latter's ability to understand the evolution of system state on the basis of a relatively incomplete sampling of the state variables.

The notion of a model as a mapping (Ashby, 1956) reveals how the effective workload of a supervisory controller can be reduced during normal system operation. The initial learning maps a subset of the physical system variables into a representation in the mind, and subsequent mappings can be made from that representation to more simplified and abstract representations of system properties. Thus a collection of variables such as *flows* and *pressures* are mapped into a representation of a component, such as a *pump*. The representations of several pumps are mapped into a *cooling system*. At each re–mapping the number of elements in the resulting set is smaller than the original, and the new set becomes semantically richer and more meaningful from the point of view of the goals and purpose of the plant. Those familiar with Rasmussen's Abstraction Hierarchy will see that in this series of mental models of mental models of ... a mental model of the physical system we are in effect showing how the operator constructs the abstraction hierarchy. Because the number of elements is smaller as the mental model becomes more abstract there is literally less workload as the operator thinks in more abstract terms.

There is more than meaning of causality, and the modern idea of causality is often impoverished. Classically, (in Aristotle and in mediaeval philosophers such as Aquinas,) there were several logically distinct kinds of causality. One might reply to the question, "Why did the steam temperature rise?", with any of the following answers: "Because the operator turned the control clockwise."; "Because the operator increased the neutron flux."; "because the operator wanted to produce more electricity."; or even "Because the thermometer reading increased.".

It is probable that each of these kinds of causality is represented by a different mental model, a different set of mappings. For example the first, classically called "efficient causality", is the kind of causality learned typically by an apprentice. The second, classically called "material causality", is what is taught at universities. If each of these kinds of knowledge is represented by a separate mental model, created by mappings from a different set of variables, it may account for the well-known difficulty of improving trouble shooting by teaching theoretical knowledge. The mapping from the physical system into the lattice of material causality is not isomorphic to the mapping from efficient causality; and indeed there may be, in training, no attempt to match them, that is to provide a cross mapping. Hence what is thought in one model cannot be mapped onto, cannot "make contact with" what is thought in the other model and theoretical training does not help operators who have a strong mental model based on field experience. Note also that in fault diagnosis there are two properties of mental model that may give rise to a massive increase in workload. Firstly, in order to identify the exact nature and location of a fault, the operator must "unpack" the abstraction hierarchy from the high level, low dimensional model back to the original model that is closest to the real system, and ultimately match a feature of the model to a physical component in the plant. This involves a great increase in the number of elements to be considered. Secondly, in unpacking the models is a one-to-many mapping, and there is no logical guarantee that the correct route back down the lattice will be followed. Both of these features, (which can be seen in Rasmussen's charts of Abstraction Hierarchy vs. Part-Whole Decomposition during fault diagnosis, (Rasmussen, 1986),) will usually greatly increase workload. In teamwork, only if operators' mental models are isomorphic to one another can knowledge be effectively shared.

It is interesting no speculate about the properties of future systems in which artificial intelligence may progress to the extent that software agents will not merely control plant processes but also try to form their own models of the properties of the human operators so as to adapt to a better symbiosis. In such systems there will be a possibility for both human and computer to misunderstand the other, and to misunderstand system functions, especially when the plant is modified without the control software being appropriately upgraded.

By definition models are always simplified representations of the original, and hence they represent a loss of information. This can be useful, because models allow extrapolation and prediction from current state, but models are also a potential source of danger and misunderstanding. Figure 2 shows some of the problems that may arise in such systems.

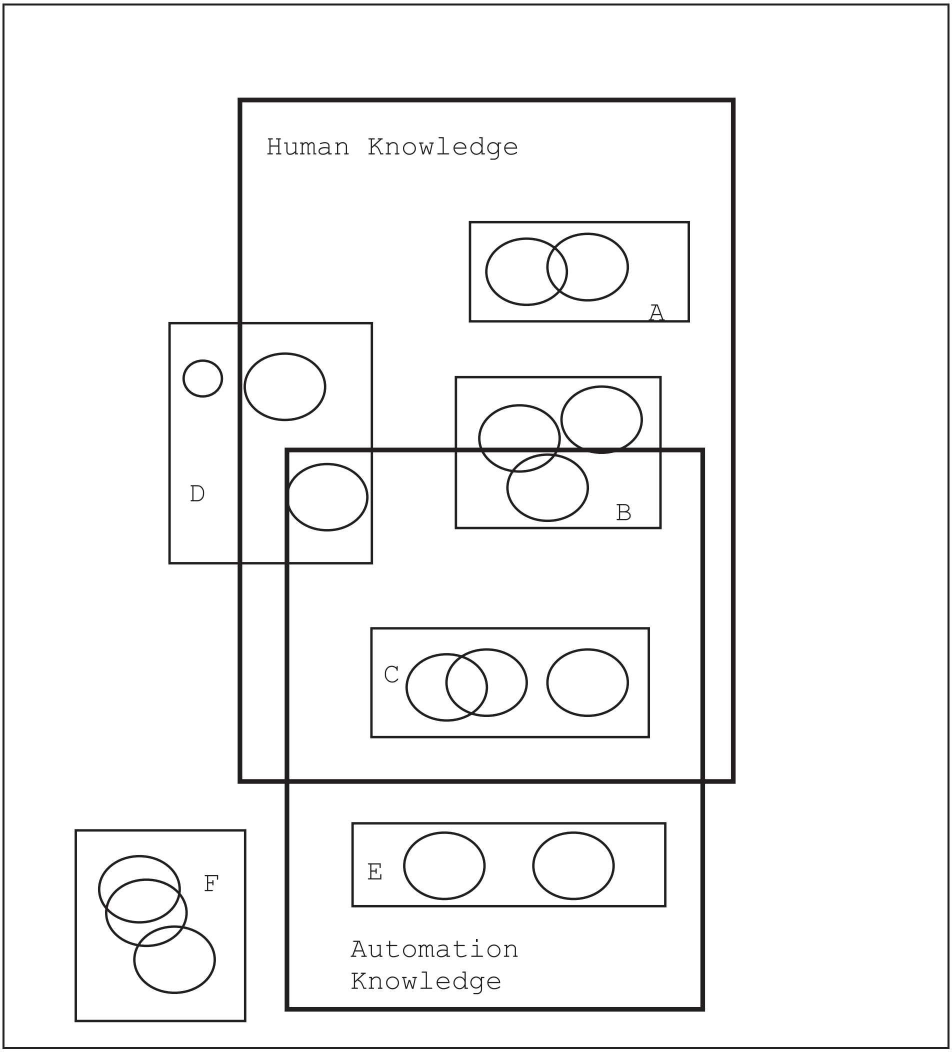



*Figure 2: A Venn diagram describing communication supervisory control. The two dark boxes contain all knowledge possessed by the human and the automation about the system's properties. The light boxes are quasi-independent subsystems. The ellipses are components such as pumps, valves, etc. Shared knowledge and understanding are indicated by the degree of overlap. The properties of subsystem A are known only to the human; of E only to the computer; of C to both. F is unknown to both. Some aspects of D are understood by both human and computer, some only to the human, and some are not known to either.*

A final problem which adds to the operator's workload arises from the question of responsibility in supervisory control. A well designed automated system should be optimised for performance in automated mode and hence the operator should seldom intervene. But the operator is also regarded as the last line of defence against system failure and accidents. As with interaction among humans, ambiguities in regard to responsibility and authority can cause delays in decision making, which may exacerbate the severity of problems. It is undesirable that humans should have the added burden of negotiating authority in time critical events. It has usually been said that human operators should retain ultimate responsibility in supervisory control, but it has been shown that in some situations, particularly time critical ones, this is undesirable (Inagaki, 1995).

## Summary

Twenty-five years after Johannsen and Sheridan organised the first international meeting on the human factors of supervisory control, we can see considerable progress. But there remains much to be done to ensure both productivity and safety in such systems. We do not have either a thorough empirical knowledge of the origins and effects of operator mental workload in supervisory control, nor a good understanding of what is the most appropriate level at which to aim to best assist operators and achieve a good human-machine symbiosis, nor do we understand how best to capitalise on the effectiveness of operator mental models. However it is a particular pleasure to note the riches yet to come in this field of research, to acknowledge the lead that has given by Gunnar Johannsen in this field, and to have the opportunity to contribute this essay in his honour.

## References


Ashby, W. R. (1956). An introduction to cybernetics. London: Chapman and Hall

Bainbridge, L. (1983). The ironies of automation. Automatica, 19, pp. 755–779

Conant, R. C. (1976). Laws of Information That Govern Systems, IEEE Transactions on Systems, Science and Cybernetics, SMC-6, pp. 240–255

Hart, S. G. and Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In P. A. Hancock and N. Meshkati (Eds.), Human mental workload, (pp. 139–184). Amsterdam: North-Holland

Inagaki, T. (1995). Situation-adaptive responsibility allocation for human-centered automation. Transactions of the Society of Instrument and Control Engineers, 31(3), pp. 292–298

Moray, N. (1997). Models of Models of ... Mental Models. In T. B. Sheridan and T. Van Lunteren (eds). Perspectives on the Human Controller. Mahwah, N. J.: Lawrence Erlbaum. pp. 271–285

Moray, N. (1999). Mental models in theory and practice. Attention and Performance XVII, Cambridge, MA: MIT Press

Moray, N. & Inagaki, T. (a) (2001). Attention and Complacency. Theoretical Issues in Ergonomics. In press

Moray, N. & Inagaki, T. (b) (2001). A Quantitative Model of Dynamic Visual Attention Based on a Synthesis of Research. In preparation

Muir, B. M., & Moray, N. (1996). Trust in automation. Part II. Experimental studies of trust and human intervention in a process control simulation. Ergonomics, 39(3), pp. 429–461

Parasuraman, R., & Riley, V. (1997). Humans and automation: use, misuse, disuse, abuse. Human Factors, 39(2), pp. 230–253

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybeernetics, SMC–30, pp. 286–297

Rasmussen, J. (1986). Information processing and human–machine interaction: an approach to cognitive engineering. Amsterdam: North–Holland

Rasmussen, J., Pederesen, A.–M., & Goodstein, L. (1995). Cognitive Engineering: concepts and applications. New York: Wiley

Reid, G. B. and Nygren, T. E. (1988). The subjective workload assessment technique: a scaling procedure for measuring mental workload. In P. Hancock and N. Meshkati (Eds.) Human Mental Workload. Amsterdam: North–Holland, pp. 185–218

Sanders, A. F. (1979). Some remarks on mental load. In N. Moray (Ed.) Mental workload, theory and measurement. New York: Plenum Press, pp. 41–78

Seiler, M. (1994). The effects of heterarchical vs. hierarchical scheduling algorithms on human operator behavior in discrete manufacturing systems. M. Sc. Thesis, Engineering Psychology research Laboratory, Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA

Sheridan, T. B. (1992). Telerobotics, automation, and human supervisory control. Cambridge, MA: MIT Press

Sheridan, T. B. (1997). Supervisory control. In G. Salvendy (ed.) Handbook of Human Factors (2nd Edition). New York: Wiley, pp. 1295–1327

Sheridan, T.B. and Johannsen, G. (Eds.), (1976). Monitoring Behavior and Supervisory Control, New York: Plenum

Sheridan, T.B. and Verplanck, W. L. (1978). Human and computer control of undersea teleoperators. technical report, Man-Machine Systems Laboratory, Department of mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Wiener, E. L. & Curry, R. E. (1980). Flight-deck automation: promises and problems. Ergonomics, 23(10), pp. 995–1011

Wierwille, W. and Connor, S. (1983). Evaluation of 20 workload measures using a psycho-motor task in a moving-base aircraft simulator. Human Factors, 25, pp. 1–16

Wilson, J. R. and Rutherford A. (1989.). Mental models: theory and application in human factors. Human Factors, 31, pp. 617–634

# Internal Models versus Cognition in Context

*M. M. (René) van Paassen*

René van Paassen obtained his MSc at the Delft University of Technology in the Netherlands in 1988. He obtained his PhD at that same university in 1994, with a thesis about neuromuscular system of the pilot's arm, for studying manual control of aircraft. After this, he spent two years as a Brite / EuRam research fellow at the University of Kassel, with Prof. Gunnar Johannsen. There he worked on the development of alternative interfaces for process control, based on functional models of the process. During a subsequent stay at the Technical University of Denmark, he put the practical experience gained in Kassel to use, in theoretical work on Multilevel Flow Modelling. Presently he works at the Aerospace Faculty of the Delft University of Technology, on aircraft simulation and human–machine interaction.

## Abstract

Models of the human operator can be used to evaluate prototype designs of systems, as a means to provide and convey insight into human operator behaviour, and as a tool to identify possible improvements to the controlled systems. Models of human cognition often incorporate an "internal model", a model of the controlled system that captures the knowledge the human operator model has about the controlled system and / or the environment. These models invariably model the cognitive processes as something internal to the human operator. Cognition at the workplace however often takes place at the boundary between the operator, the system and the environment. Intermediate results of cognition can for example be stored in the system (c.f. the use of an abacus for calculations). If the purpose of a model of the human operator is to provide insight or to aid in improving the interface and workplace, adequate modelling of cognitive processes that cross the boundary between the operator, system and environment is needed.

## Introduction

The design phase of a complex system, such as an airplane, power plant, a multimedia device, a website, starts with the desires of the "client" and the constraints of the environment. These are translated into the goals for the system, and ways are found to satisfy these goals through existing, modified or new designs. Any good design should consider the interaction between the system and its users, and try to determine the behaviour of the combined human–machine system.

One valid approach to achieve this is the formulation of models for the human operator that are compatible with the models and descriptions of the system being built. The behaviour of the human operator is modelled in the same domain that is chosen to represent the knowledge of the new system, for example as a computer model, or as a mathematical description, often in the control theoretic domain. This brings knowledge about the "user" or operator and the system together in a compatible representation.

Note that there are also other ways to find the answer to the question of how the combined system will perform. Most notably, prototyping and the development of simulations in which the users can be confronted with the system in an early stage, and solicitation of the opinion of "experts", who know both the work domain and have engineering and human factors knowledge can evaluate a design.

Models of human operator behaviour have been applied successfully in the past to describe the interaction of a human operator and the system he is controlling. If one takes the three levels of interaction proposed by Rasmussen (1983) as a meaningful classification, then one must say that we have been most successful at modelling the human operator's skill-based behaviour. Models of rule-based behaviour and knowledge-based behaviour have also been developed, but in general these models are less generic; they have to be fed with a considerable base of knowledge about the specific application domain.

Any meaningful interaction between the human operator and his surroundings, i.e. the system he is controlling and the environment, requires that the behaviour of the human operator is adapted to these surroundings. It is assumed that the human operator has knowledge about the state of his surroundings. This knowledge is called the "internal representation" (Stassen, Johannsen, & Moray, 1990).

Often the knowledge that a model has about its surroundings (in this case the modelled system and the modelled environment) is captured in a so-called "internal model" (Stassen et al., 1990). The state of this internal model tracks the state of the environment, and operator control actions are based on the state of the internal model. Depending on the domain of the model, techniques from control theory (for modelling of skill based behaviour) or from artificial intelligence (for rule and knowledge based behaviour) are used to drive the update of the internal model and the formulation of control actions.

This paper signals two disadvantages with this approach. The first is that the cognition is modelled as a process that is internal to the human operator. Accounts of "cognition on the job" indicate that this is often not true, cognitive work is being performed in a continuous interaction between the operator and his surroundings, and often these surroundings play a significant role in obtaining the cognitive result or storing intermediate results. The second disadvantage is related to the first, and that is that the modelling of the interface between the operator and his environment does not always get the attention it deserves, simply because the model of the operator and his surroundings have already been brought to the same "language", and information exchange between operator model, system model and environment model can be done directly. However, in the case that cognition takes place across the border of the interface between operator and surroundings, then the properties of this interface are likely to be important for the resulting cognitive process, which requires that these properties are correctly reflected in the model as well.

## Operator models for skill-based interaction

A set of successful and widely applied models, in this case for the description of manual control tasks performed by human operator, are the models developed by (McRuer & Jex, 1967). These models describe the behaviour of a human controller, given a control systems model of the system that is controlled by the human. The restrictions are that the controlled system is a continuous, linear, not time-varying single-input, single-output system, or that it can be considered to be a good approximation of such a system.

One of these model variants, the "simplified precision model" consists of a simple transfer function, with a lead term, a lag term, a time delay and a gain:

$$H_p(j\omega) = K_p \frac{1+\tau_L j\omega}{1+\tau_l j\omega} e^{-\tau_e j\omega} \tag{1}$$

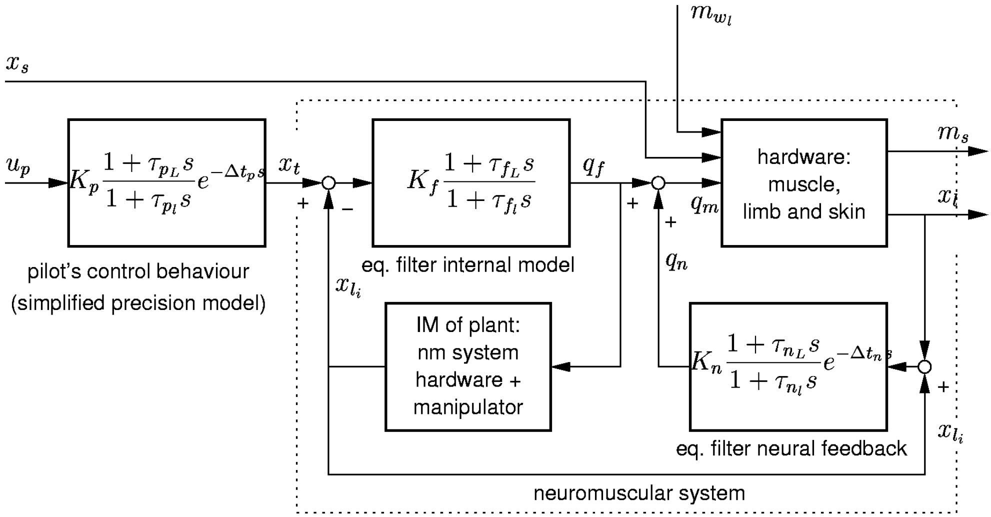
The human operator can adapt his control behaviour to the task at hand, and in the simplified precision model this is reflected by the fact that the parameters of the model can be adjusted to produce the desired control behaviour. The general rule is that the human operator adjusts his control behaviour so that combined open loop of the human operator and the controlled system has characteristics in the region of crossover, which is defined as the cross-over model:

$$H_{olp}(j\omega) = H_p H_c = \frac{\omega_c e^{-\tau_e j\omega}}{j\omega} \tag{2}$$

In order to obtain this behaviour for the simplified precision model (Eq. 1), a set of six rules is given to determine the parameters of that model of Eq. 1. For the application of these rules, one needs knowledge of the controlled system and of the disturbances on that system.

Thus, as most models of human behaviour, the simplified precision model requires knowledge of the system that the human interacts with and knowledge of the environment, which is in this case coded in the choice of the pilot equalisation parameters. This is some form of internal model, but in this case the internal model is not made explicit in the modelling process.

Many models go one step beyond this, and capture the knowledge of the system and environment as an explicit internal model. An example of this is the optimal control model (OCM), (Kleinman, Baron, & Levison, 1970). Here an internal model is used in a Kalman filter that forms a state estimate of the state of the controlled system. An optimal controller, also part of the human operator model, then uses this state estimate to control the system. The internal model is usually a full copy of the model used by the modeller for the real system,




which implies that the operator model has full and correct knowledge of the system structure, and of the statistical properties of any disturbances on the system. To account for limitations of the human operator, sensor noise and motor noise are postulated for respectively the observations made (input to the state estimation) and the control outputs.

An explicit internal model captures only a part of the knowledge about the controlled system that the model of the operator needs. Consider for example Figure 1, which presents a model of the neuromuscular system (Paassen, 1994). In the human (or any other animal's) neuromuscular system, the signals travelling to and from the muscles are subject to time delays introduced by the neural system. If these time delays are taken into account, fast movements as in sports or in playing musical instruments would not be possible, control of the muscles would be slowed by these delays. It is therefore hypothesised that humans use an internal representation of the neuromuscular system and load to generate control signals in an open–loop fashion (Schmidt, 1981). Experiments with disturbances applied during fast movements provide supporting evidence for this (Happee, 1992). The model in Figure 1 captures the ability of a human (or other animal) to generate fast "open–loop" movements, and combine it with the feedback from sensors in the limb and muscle to correct for external disturbances. The internal model is explicit here, and taken to be exactly the "true" external model for the manipulator that is moved by the operator's hand. However, aside from the knowledge that is put into the model by means of the "internal model", also the parameters of the equalisation filter for the internal model and of the equalisation filter for the neural feedback must be adjusted to the characteristics of the manipulator to be used.

*Figure 1: A model of the pilot's control behaviour, with detailed modelling of the neuromuscular system. This model uses an explicit internal model. In addition, the parameters of the equalisation filter for the internal model and the equalisation filter for the neural feedback must be tuned to the properties of the combination of muscles, limb and manipulator. Here,* $m_S$ *is the moment exerted on a manipulator,* $x_l$ *is the position of the limb,* $q_m$ *is the control signal for the muscle, and is the sum of the control calculated on basis of the internal model,* $q_f$, *and the neural feedback* $q_n$. $x_{li}$ *is the predicted limb position of the internal model,* $u_P$ *is the visual input of the pilot,* $m_{Wl}$ *is a disturbance on the limb.*

## Rule and knowledge–based behaviour

The optimal control model and the crossover model both describe an aspect of the skill–based behaviour of the human operator. Following Rasmussen's widely used distinction into three levels of human operator behaviour, i.e. skill–, rule– and knowledge–based behaviour, operator models for other types of behaviour are also made.

One of the earlier examples is PROCRU. This is a model based on the optimal control model, which has been enhanced with a set of (deterministic) rules that describe the rule–based behaviour of a pilot. Rule–based actions are started as soon as the observed state from the Kalman filter matches a rule. It is assumed that any rule–based actions, which have an associated time slot, temporarily stop the observation of the controlled process, leading to increased uncertainty in the state estimate and a corresponding error in the control input.

An example of a model that should support a mix of rule and knowledge–based behaviour is MIDAS (Corker, 2000). This is an extensive model of human operator behaviour, of which the modelling system can be operated via a graphical user interface. This model uses an explicit internal model, termed the "Updateable World Representation".

A model that can, with the proper addition of knowledge and reasoning, function as a model of knowledge and rule–based behaviour, is IDA (Smidts, Shen, & Mosleh, 1997). IDA, (which stands for Information, Diagnosis / Decision, Action) has been applied in probabilistic risk assessment for nuclear power plant operations. It does not use an explicit internal model, but the necessary knowledge for interaction with the world is captured in a long––term memory database. It explicitly includes limitations for memory and processing speed.

## Limitations of the "internal model" approach

Overseeing the range of human operator models created in the past decades, one cannot fail to notice a parallel between the development of human operator models on the one hand and the development of control theory and – for the more cognitive models – software and knowledge engineering on the other hand. In particular, advanced cognitive models can be admired as a work of state-of-the-art software engineering by themselves, featuring tools such as knowledge bases, symbolic and semantic processing and goal-oriented behaviour.

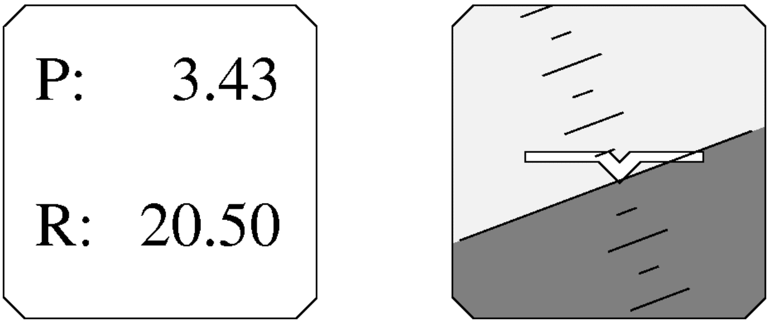



*Figure 2: Two display presentations for pitch and roll angle that are both clearly readable. The cross-over model would not be different for these configurations.*

These models are often successful in mimicking human operator behaviour. However, mimicking behaviour is not enough to make a model useful. Several uses of a human operator model can be distinguished:

- As a means for the verification and testing of a system design. This is for example the purpose of the IDA model; the mechanised description of human operator behaviour in IDA makes it possible to perform for example probabilistic risk analyses.
- As a vehicle for understanding. For this purpose the model should give insight into the functioning of the human operator.
- As an aid in design. For this purpose the model should have a predictive capability, so that the overall system performance can be calculated for a specific design. The cross-over model by McRuer, in combination with the adjustment rules, can fulfil this function in some cases.

For the first use, mimicking of human operator behaviour is enough. For the second and third purpose, the model should not only mimic behaviour, but also imitate the underlying processes that generate this behaviour. The tendency in combining a model of human operator behaviour and a model of the controlled system is that one removes the interface.

What is easier than starting up Matlab, entering a transfer function for the controlled system, entering (an approximation of) Eq. 1, and calculating the combined system performance? However, this omits the fact that signals from the system have to be presented on a display, and that control inputs from the pilot have to be transferred to the system. This is a well–known deficiency of for example the cross–over model, any of the displays of Figure 2 for example would – according to the model – deliver the same performance. In theory, if the "noise" inherent in observations from a specific type of display could be adequately expressed as observation noise, the optimal control model could be used to predict the effect of display characteristics. However, the problem of this model is that it does not predict human limitations; optimal control models of arbitrary complexity may be applied, while it is not guaranteed that human operators will be able to behave as the model. Also, in practice it appears that the OCM still requires considerable tuning to match observed operator behaviour.

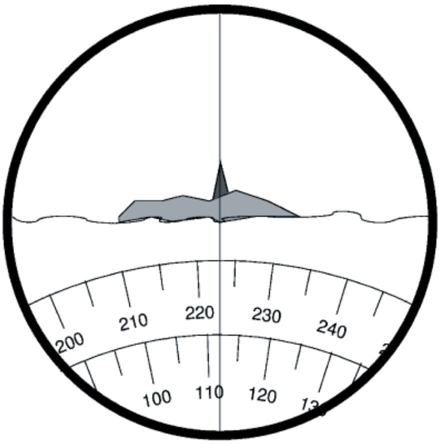



*Figure 3: Reading off a scale to the degree, when ten–degree intervals are presented in numbers, is a cognitive task with multiple steps (from Hutchins, 1995).*

In models of cognitive behaviour, such as IDA, one can see that the cognition fully takes place inside the human operator, something appropriate for a chess player playing a blind match. IDA's information module picks up all relevant information from the environment and places it in working memory, and rules from the knowledge base (modelling long term memory) that are recalled into working memory can apply transformations to this information. It is doubtful that such a characteristic is typical for cognition at the workplace. MIDAS relies even more on this paradigm, because it uses an explicit internal model. However, it appears wrong to assume that everyday cognition at the workplace is a matter of internalising the relevant information and then performing all cognition "on the inside".

A different view on the nature of cognition by operators is given in the description of the cognitive processes for navigation on board navy ships, by Hutchins (1995). From this description, it becomes clear that:

- Cognitive tasks are approached in small steps. For example reading off a scale such as the one in Figure 3 could be described as (1) reading of the major numbers to the left of the heading mark, (2) estimating the decimal fraction, (3) combining the two.
- Cognition takes place in the context of the operator's surroundings, and continuously crosses the boundary between the operator and the system and environment. For example, aligning an alidade (a sight used for determining lines of position on a ship) with a landmark means that the orientation of the landmark with respect to the ship is coded into the alidade.

The point that has to be made here is that cognition at the workplace is not a sequence of: (1) Observation of external variables, conversion into an internal representation. (2) With the internal representation, search for the applicable procedures / rules or apply knowledge inference to obtain the conclusion. (3) On the basis of the updated internal representation of the system, act. (4) Return to 1.

Rather, it appears to be a sequence of coordinating chunks of information that may reside in the system, the environment or the operator's mind or which may be coded as a combination of these three. To summarise an example from (Hutchins, 1995), when looking for a landmark on a shoreline, a sailor would coordinate his knowledge of the landmarks on the shore (e.g. a high-rise building, a tower, a pier) with the shoreline he is seeing. The result of this cognitive action is not some piece of abstract knowledge in the sailor's mind, instead it is the physical orientation of the sailor in relation to the environment, in other words, the fact that he is looking at the landmark in question. The following step in this cognitive task, already quoted above, is that he will align his alidade with the landmark. Now the information is coded in the position of the alidade, and he can take his eye and attention from the landmark, to carry on with the remaining elements of his task.

This example shows that cognition crosses the border between the operator, the system and the environment. Not just at the point where the dials are read and the reasoning starts, but, at least in a well-designed system, continuously, all the time. Such behaviour cannot be caught with operator models that are based on explicit internal models of the system and environment, because in these models all cognition will be done within the operator's head.

## Situated Cognition

The fact that cognitive processes often take place at the border of the human operator and his surroundings also signifies that there is a large influence of the surroundings on the cognitive process. The design of the system, which in the context of human–machine interaction includes the design of the displays, support systems and in general of the combined human–machine system, can therefore strongly influence the cognition that will take place. Here it is not an issue of answering the question whether the numbers or other indications of a display can be read, it is an issue of answering the question whether the information on a display is useful in the context of the cognitive steps that have to be taken in the task.

An approach that exemplifies the design of an interface and support for cognition is Ecological Interface Design (Vicente & Rasmussen, 1990, 1992). Interfaces designed with this technology show the relations between the control functions available to the operator, and the goals to be achieved with the system, usually displaying the process at intermediate levels of abstraction. The interface then forms a template for goal–oriented reasoning, the relation between the control inputs and the functioning of the system is then visualised on the screen, instead of only represented in the experience of an operator.

## Conclusions

Development in models of the human operator progresses along with the development of computational power and our ability to describe complex processes in a form that can be processed by a computer. This leads to models that, with increasingly accuracy, describe and capture the complex behaviour a human operator can display. One purpose of these models is to mimic human behaviour, so that predictions of, for example, reliability of the combined system can be made. Without such models, the evaluation of the system reliability would become prohibitively expensive in terms of manpower and time.

However, two more uses that might be more important may not be neglected, namely the models should provide further insight into human behaviour, and they should be useful in improving a design. Modelling approaches that are based on the assumption that human cognitive behaviour takes place "on the inside", i.e. only in the human's brain, fail to adequately address these uses. Cognition is often shared between the operator and his surroundings, and intermediate steps in cognitive tasks may have a result that is coded in as information in the operators head, as information in the system or as information diffused between the system, operator and the environment. Modelling approaches that consider this distributed aspect of cognition are needed for the design of systems that support cognition at the workplace.

## References


Corker, K. M. (2000). Cognitive models and control: Human and system dynamics in advanced airspace operations. In N. B. Sarter & R. Amalberti (Eds.), Cognitive engineering in the aviation domain (pp. 1–42). Mahwah, New Jersey: Lawrence Erlbaum Associates

Happee, R. (1992). Adaptation of unexpected variations of an inertial load in goal directed movements. In 5th IFAC congress on the analysis, design and evaluation of man-machine systems. The Hague

Hutchins, E. (1995). Cognition in the wild. Cambridge, Mass.: MIT Press

Kleinman, D. L., Baron, S., & Levison, W. H. (1970). An optimal control model of human response part I: Theory and validation. Automatica, 6, pp. 357–369

McRuer, D. T., & Jex, H. R. (1967). A review of quasi-linear pilot models. IEEE Transactions on Human Factors in Electronics, 8, pp. 231–249

Paassen, M. M. van (1994). Biophysics in aircraft control – a model of the neuromuscular system of the pilot's arm. Unpublished doctoral dissertation, Faculty of Aerospace Engineering, Delft University of Technology, Delft

Rasmussen, J. (1983). Skills, rules and knowledge; signals signs and symbols, and other distinctions in human performance models. IEEE-SMC, 13 (3), pp. 257–266

Schmidt, R. A. (1981). Motor control and learning – a behavioral emphasis. Human Kinetics Publishers, Champaign Illinois

Smidts, C., Shen, S. H., & Mosleh, A. (1997). The IDA cognitive model for the analysis of nuclear power plant operator response under accident conditions. Part I: problem solving and decision making model. Reliability Engineering and System Safety, 55, pp. 51–71

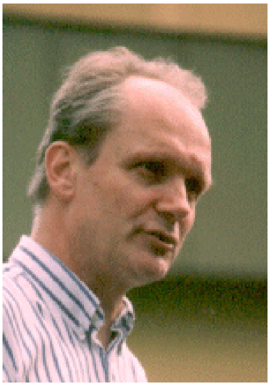
Stassen, H. G., Johannsen, G., & Moray, N. (1990). Internal representation, internal model, human performance model and mental workload. Automatica, 26 (4), pp. 811–820

Vicente, K. J., & Rasmussen, J. (1990). The ecology of human-machine systems ii: Mediating "direct perception" in complex work domains. Ecological Psychology, 2 (10), pp. 207–249

Vicente, K. J., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundation. IEEE Transactions on Systems, Man and Cybernetics, 22 (4), pp. 589–606

# Human Process Control and Automation – still compatible concepts?

*Reiner Onken*



Reiner Onken, 1969 PhD at TU Braunschweig, 1970 NRC Associate with NASA Ames Research Center, Director of the departement "Steuerung und Regelung" of the DLR-Institute "Flugführung" (in this function first contacts with Prof. Johannsen). Since 1985 Professor for Flight Mechanics and Aeronautics at the University of the German Armed Forces, Munich, Member of AIAA, DGLR

## Introduction

There is no doubt, since its introduction automation has led to great increases of process control productivity, comprising both process / cost effectiveness and safety aspects. The functional blend of human work capacity and automatic aids has been a permanent success. This is true across the application domains, including power plant as well as vehicle control, for example. Throughout the evolution of more and more replacement of human work domains by automated functions, also as a consequence, the realm of human engineering and man-machine systems has been increasingly flourishing, too [Johannsen, 93].

With progressive impact of automation in human-controlled processes, however, we are encountering new kinds of problems, in particular regarding the human operator's resource management and situation awareness. The wording "Ironies of automation" [Bainbridge, 87] has become a common catch phrase. Experiences with highly complex automation in modern systems are revealing inevitably troublesome properties like brittleness, opacity, literalism and clumsiness [Billings, 97]. Thereby, new types of process collapses and accidents have come up. It is a fact that there is no significant decrease of relative accident rates in commercial air traffic (accidents / departures) since 15 years despite of heavily increased endeavours in cockpit automation. The crash of a commercial airplane close to Cali, Columbia, in 1995, professionally described by [Baberg, 00], is just one of many striking examples for the new types of mishaps which can be related to the aforementioned upcoming problems of automation.

Does that mean that the concept of automation has come to its limits?

In the following of this article it will be worked on this question. It is true that conventional automation technology does not seem capable to get rid of the limiting problems. New approaches on the basis of information technology, however, lead to new promises under a different notion of automation, which is called "cognitive automation", based on cognitive engineering. The focus of cognitive automation is on the whole system including the processes in the deeper layers of interaction between man and machine and, thus, not solely on problems at the surface of the interface (*"... you will not correctly assess the iceberg if you do not take into account that the emergent part, the pilot interface, is the result of a* *tremendous underwater mass of ice"*, [Fabre, 97]). Cognitive automation lends itself to interact more efficiently with human cognition in terms of cognitive cooperation. This also leads to a revised definition of automation as such.

## What is cognitive automation?

The difference between cognitive and conventional automation can be easily illustrated by Rasmussen's scheme of human cognitive behavior (see Figure 1) which became widely known in the eighties [Rasmussen, 83]. As shown in this figure, conventional automation covers only about half of the functional elements which are part of human cognition. In particular, the formation of a comprehensive picture of the situation, which takes all three behavioral levels (feature formation, recognition, identification), is very sparsely covered in conventionally automated systems.

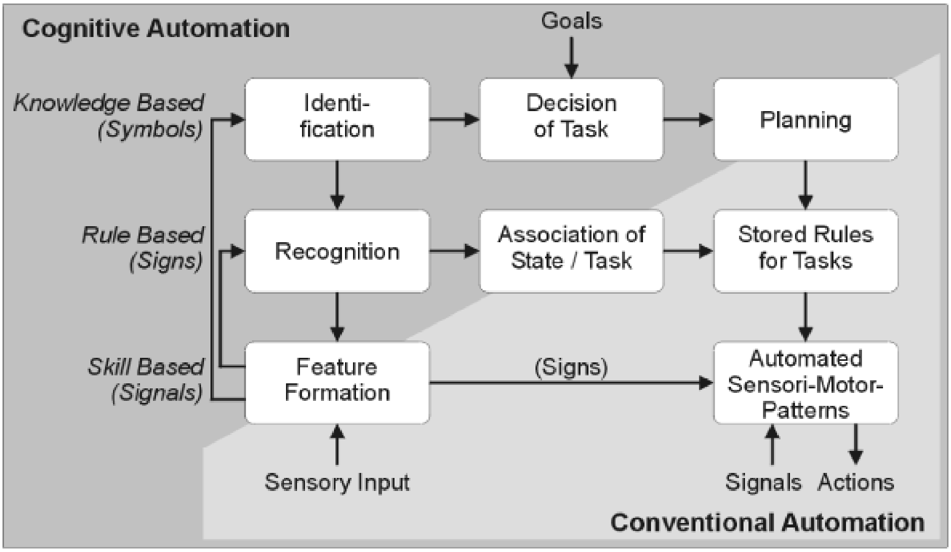



*Figure 1: Conventional vs. Cognitive Automation*

Therefore, it is not surprising that conventional automation cannot do much to support human operators regarding situation awareness. A conventionally automated function only detects those features of the situation which are dedicated to this particular part function. Usually, this is a small number of the whole of relevant features describing the semantics of the actual situation of the work process. The autopilot altitude mode, for instance, senses the altitude but does not recognize the mountain in the way. Conventional automation also does not incorporate explicit knowledge about the governing productivity objectives pertinent to the work process. Consequently, the features which are specified by the designer to be detected and displayed to the operator as part of automated functions cannot reliably be associated to the process objectives in terms of importance or urgency. Therefore, conventional automation can either warrant reliable identification of the situational relevance of those features. In turn, harmful outcomes of automated functions cannot be avoided reliably, unless the designer has taken care of it or unless the human operator is detecting the corruptive effects in due time. All this, in the light of the other aforementioned problems makes it not easier for the human operator to maintain situation awareness at all time. This makes it necessary to look for system requirements to ensure situation awareness of the human operator.

In contrast, cognitive automation, by definition, has got knowledge-based capabilities

- to independently assess and keep ready necessary situation-relevant information about the objectives the human operator is pursuing, about his intents and activities, about the work object and tools, and about the relevant process environment
- to understand the situation by independently interpreting it in the light of the objectives
- to detect the operator's errors
- to know which information the operator needs
- to support necessary re-planning and decision making

and

- to initiate human-like communication to ensure that the operator's situation awareness is evened up with what is detected as conflicts or opportunities by the systems, not to leave him alone with presentations which do not care about what he has understood about the situation and what he actually perceives or does not perceive.

Cognitive automation works in similar ways as the human operator, founding its activities on the knowledge about the governing process objectives as they are known by the human operator, too. Cognitive automation, though, should not be aimed at copying human behavior and excellencies. It should rather take advantage of dissimilarities in performance, in particular it should complement performance properties, where the human operator may show weaknesses, may be at the expense of performance drawbacks, where the human operator's excellencies are.

## The Cognitive Process

To implement the cognitive approach as a technical process human cognition provides a good guideline. The following functional core elements can be identified:

- Situation monitoring (perception and interpretation)
- Diagnosis of the situation
- Decision making and / or planning
- Execution / activation

These functional elements are forming the cognitive loop as shown in Figure 2. The environment of the cognitive process, which is named the real world, presents stimuli, which can be detected by different kinds of sensory systems. All relevant stimuli from the environment of the cognitive process are taken into account. This represents the functional element of perception of all relevant elementary situation features. It is closely interrelated with the process of situation analysis in order to achieve a certain level of abstraction, thereby establishing situation–relevant "objects" which help to understand what is different between the expected and actual situation. These differences are dealt with in a higher level of abstraction by the so–called situation diagnosis process. The differences are evaluated against given objectives, the relevant goals, which are known to be pursued during the work process, and which are the same the human operator has in mind. Only the knowledge about these goals makes situation awareness possible in the technical cognitive loop. Thereby conflicts and / or opportunities may be detected which may call for immediate actions or some action plan changes.

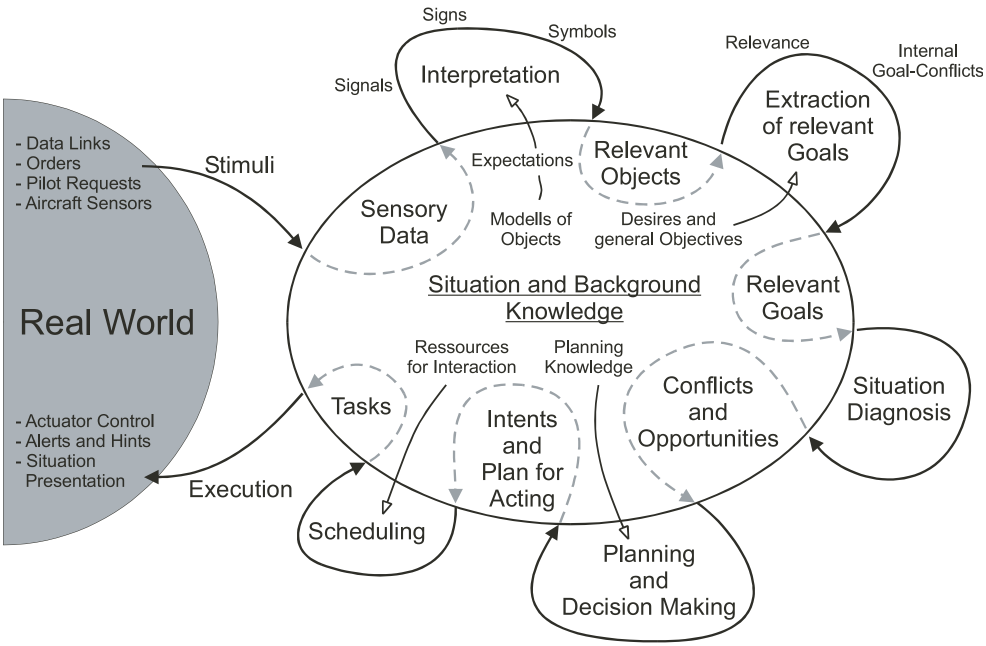



*Figure 2: The Cognitive Loop*

In the latter case a *planning process* is activated to generate alternatives for interim–goals, plans, and actions. In compliance with the given overall objectives, the most appropriate ones are chosen for proposals.

Concerning the cooperation aspect, also the execution element of the cognitive process plays a very central and important role, as it includes the communication with the crew. Communication is carried out on the basis of profound internal knowledge about what information the human operator is looking for, why and when. On the other hand, the human operator should at any time be able to ask for certain information within the system. A sophisticated, multimodal MMI is required which adapts to the mental models of the human operator and his interaction to accomplish this task.

It also takes into consideration that the human operator may react differently compared to what the system has proposed. There is only the consequence that new stimuli result for the cognitive loop, which in turn starts over again and copes with the operator's action. The feedback via these stimuli creates a kind of implicit communication.

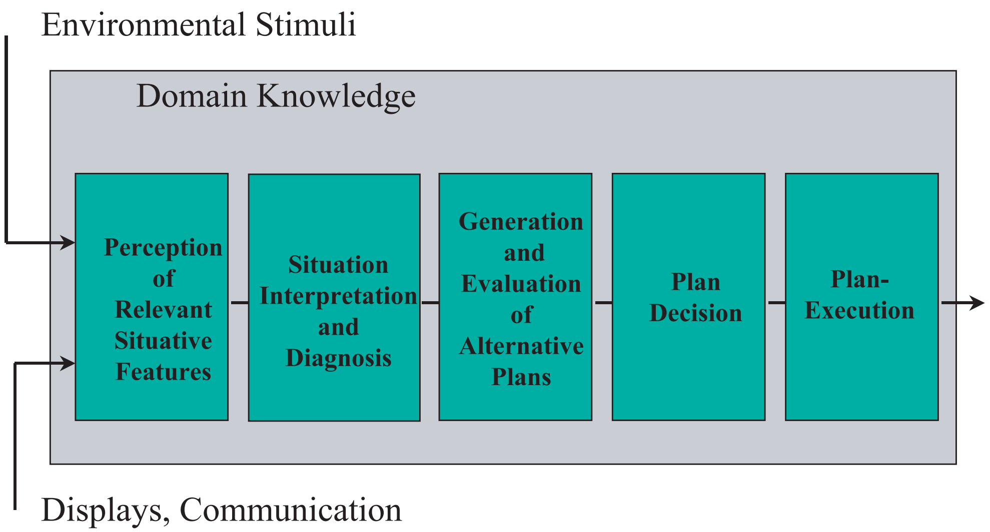
Further details of realization can be looked up in [Onken, 00], for instance. This is the change needed which will provide really effective means for the sake of work process productivity.

### The changing role of automation

The role of automation, when going for cognitive automation, will change as technological potentials grow. In the following it will briefly be dwelt on this potentially expanding role.

The human interaction with the real world happens in so-called work processes. A work process is described by the functions performed to obtain a desired product [Winter et al., 95]. Figure 3 shows, with great similarity to the cognitive loop in Figure 2, the generic cycle of subfunctions pertinent to each domain-specific main function of a work process, including sensing, information processing and effecting functions. All of these functions draw on domain knowledge.

*Figure 3: Generic subfunction cycle, pertinent to all main functions of domain-specific work processes*



Another way of viewing at human work is the system representation. This leads to the so–called work systems. The work system is to pursue the same objective to accomplish a desired product. It consists of the following components: Human operator, work object and tool(s). The work object can be any kind of object, people, machines or any kind of natural or artificial object, also abstract ones. The tools are technical devices or machines and should be helpful to accomplish the objective. In general, the operator can directly interact with the work object or he can deploy tools.

Looking at these representations, both can be used to describe the role of automation [Johannsen, 93]. The representation by work processes, however, is better suited for this purpose, since it directly reflects the activities associated with automation. The system representation may contribute to the misleading conclusion that automation is represented by the tools only. Of course, the tools are pertinent to the automation components in the work system and are clearly recognized as such by the operator, but automation goes beyond that. For example, considering the ABS system in cars, this is pure automation and it is obviously part of the work object, since the driver cannot use it as a tool by activating or deactivating it. On the other hand, since the work is shared by the operator and automated functions, there have to be additional work processes taking care of the interactions between automated functions and the human operator. Those can also be represented in accordance to the functional scheme in Figure 3, for both the human operator's activities (tasks) and the automated interface functions.

Staying with the work process representation, then the role of automation can easily be described by fulfilling certain functional needs within the work process and by the degree of authority which is given to each of these automated functions by either the system designer or the operator.

Regarding conventional automation, this has led to the firm allocation of automated functions in the work process, activated by the human operator or automatically released as laid down by the design specifications. As an automated function is activated, this function is completely carried out by automation. Thereby, the human operator is freed of a task and has no longer to be involved in that. Vice versa, if the human operator decides to cover a certain work process function by himself, which could be taken over by an automated function, this automated function stays deactivated. It is at the disposal of the operator for the particular piece of work it is designed for. It is carrying out something it is charged for, not knowing explicitly whether this is of any benefit. The role of conventional automation is that one of a servant only knowing about how to carry out a certain instruction without intentionally caring for the overall consequences.

Considering cognitive automation, the automated functions as part of the work system are upholding a role of automation as a subordinate electronic teammate for the human operator (Figure 4). Taking this role of a teammate like the role of a human teammate, it is not only carrying out instructions of the human operator but understands also why this instruction was given and has even got the knowledge to reason, whether, from its own point of view, this instruction is complying with the governing objectives of the work process. Thus, with cognitive automation, both the human operator and the electronic cognitive teammate have got similar cognitive capabilities, however usually with different performance levels with respect to each of these capabilities in order to rather complement each other. Therefore, cognitive automation can be exploited for a role as an electronic teammate to function in parallel to the human operator in the work process in order to be able to offer advice if wanted by the human operator, or to take over, if the human operator so decides as the team chief. In its ultimate case, for instance in a situation, when the human operator would not be able to avoid a catastrophe, there can be even the exceptional role of taking over without specific authorization by the human operator. Within this range, the role of cognitive automation may change considerably throughout the course of the work process.

On the basis of the preceding considerations about the changing role of automation, also some redefinition of automation is appropriate. As a result, one can conclude in general terms (close to [Billings, 97]):

**Automation is a technical resource to improve the productivity (usually regarding process / cost effectiveness and safety) of a work process by making use of its own capabilities to carry out low level as well as high level cognitive functions which are needed along the work process and which otherwise the human operator would have to perform without any aid.**

**Automated functions, whether on the basis of conventional or cognitive automation, have to be specifically authorized, either by the design, when implemented as built-in automated functions or by the human operator.**

This covers automation of

- information gathering functions (sensing, communication)
- information processing function (management, control)
- effecting functions (information presentation, actuation).

There is still the question about how to measure the level of automation. So far, the level of automation (LoA) was the range of functions in the work process, for which the human operator is replaced by automation. This can be called dimension 1 of LoA.

On the basis of the aforementioned general redefinition of automation, however, including cognitive automation, two additional dimensions have to be supplemented:

**With the dimension 2 of LoA one has to account for the level of cognitive capabilities within the automated functions (competency level).**

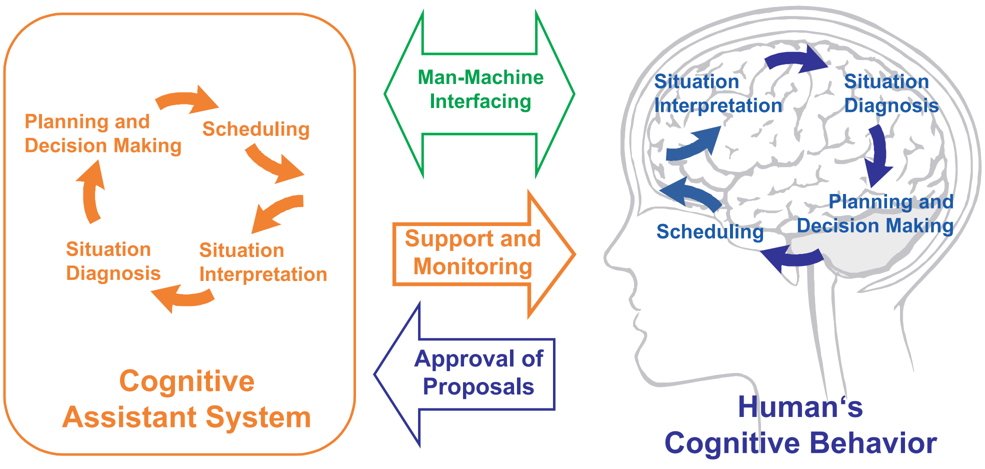
**With the dimension 3 of LoA one has to account for the range of those automated functions in the work process, which both the human operator and the automation part of the work system might simultaneously and cooperatively work on. These functions typically involve cognitive capabilities and inter-communication initiatives from both sides for performance enhancement.**

The latter dimensions of LoA are good indicators for the ongoing change of the role of automation towards an electronic teammate providing cognitive cooperation.

## Cognitive Cooperation

The role of cognitive automation as an electronic teammate (Figure 4) for the human operator can be exploited for cognitive cooperation. If it can be accomplished that this electronic teammate has got sufficient knowledge about the work domain, the governing objectives of the work process and the human team chief, mutual understanding can be achieved on the cognitive level which is unprecedented. Foremost, dimensions 2 and 3 of level of automation give an indication how far cognitive cooperation can be extended, for instance to balance out discrepancies in situation awareness. Thereby, the LoA provides an indication about the depth of situation awareness, for instance, as it can be achieved by the electronic teammate in parallel to the human operator.

*Figure 4: The cooperative cognitive approach by use of a cognitive assistant system*



Consequently, two basic functional requirements can be formulated for use of automation in the sense of cognitive cooperation with the human operator:

- Basic requirement (1)
  It must be ensured full situation awareness of the human operator, including that the attention of the human operator is guided towards the objectively most urgent task or subtask as demanded in the actual situation.
- Basic requirement (2)
  A situation with overcharge of the human operator might come up, even when situation awareness has been achieved. In this case, automation has to transfer the situation into a normal one which can be handled by the human operator in a normal manner.

These requirements are in line with what is defined as human–centered automation by [Billings, 97] and others.

It takes a technical cognitive process as shown in Figure 2 in order to fulfill these requirements. There are a number of developments of cognitive design which are in some compliance with the requirements and which partially already have proved the effect of productivity increase in simulator and field tests as described in [Lizza et al., 91; Champigneux, 95; Heßler, 89; Dudek, 90; Funk, 98; Gerlach et al., 95, Kopf, 94; Johannsen, 97; Frey et al., 99; Borys, 00]. Further developments will follow with refinement in situation feature perception, refinement in the knowledge bases about situational objects, hierarchy of work process objectives [Walsdorf, 00] and behavior of the human operator [Sundström, 93; Stütz, 97; Strohal, 98; Jürgensohn, 97; Krüger et al., 00], partially by automatic learning [Grashey, 99; v. Garrel et al., 01], and refinement of system structure.

## CAMA – a prototype for cognitive cooperation

CAMA, the Crew Assistant Military Aircraft [Frey et al., 99], is a cognitive assistant system prototype for the domain of military transport aircraft. It is based on its predecessor CASSY (civil transport aircraft domain, flight tested in 1994 [Gerlach et al., 1995]) and was developed in close cooperation with DLR, EADS, and ESG.

Situation data is fed into a Central Situation Representation and situation interpretation modules like a Tactical Situation Interpretation and a Terrain Interpreter (Figure 5). On the basis of the expected individual pilot behavior (using Petri net representation and Case–based Reasoning) is established and compared with actual behavior by a fuzzy–neuro Intent and Error Recognition.

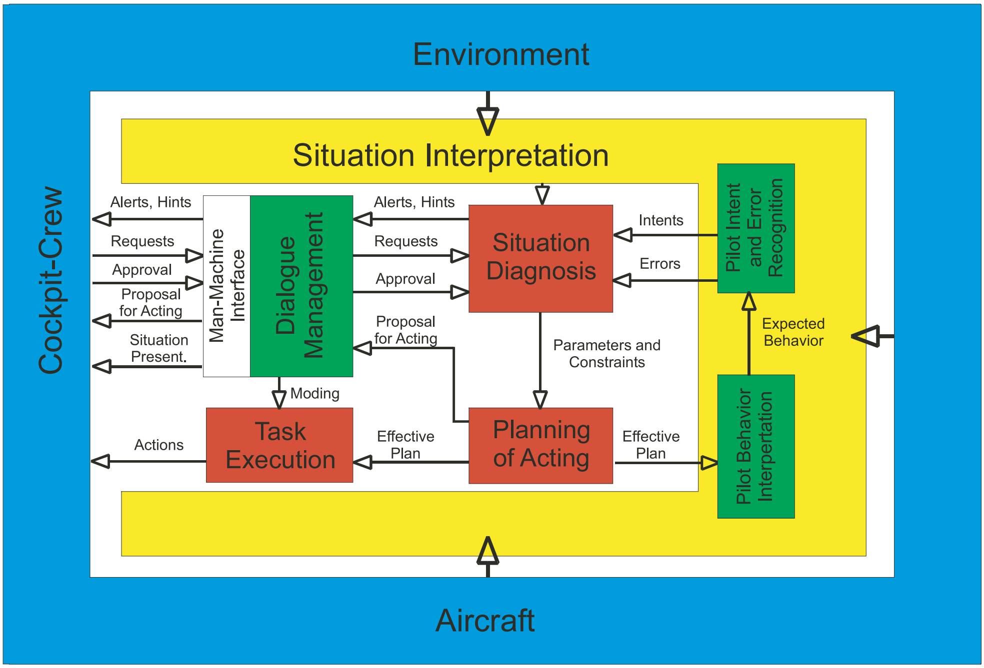



*Figure 5: Functional structure of CAMA*

If conflicts are detected by the Situation Diagnosis module, problem solving modules like a low level flight planner inside the mission planning module are started. Problem solutions are communicated between CAMA and the pilot crew through a Dialogue Manager module which uses speech communicaton in multimodal combination with situation displays and touch screen input.

CAMA was intensively tested in the flight simulator and and successfully flight tested [Frey et al., 01]. The main scenario was characterized by a typical military transport mission with both low level and civil–IFR (Instrument Flight Rules) flight phases.

The evaluation contained subjective ratings, regarding usability and realism of the test environment, influence on pilot's situation awareness, assistance quality of the system and pilot's acceptance. The results were highly convincing. Cognitive cooperation appears to be the salient solution to keep the human–electronic team well productive.

## Conclusions

As a conclusion, referring to the title of this article, human process control and automation are still compatible concepts, if automation is designed appropriately.

The advances in cognitive engineering technology have brought about means to systematically reflect requirements for human–centered automation into clear–cut specifications. The basis for this is a new notion of automation, the so–called cognitive automation. Cognitive automation in turn results in a changing role of automation and a revised general definiton of automation and level of automation.

There is the prospect that cognitive automation can indeed lead to cognitive cooperation as it is required since long. Unprecedented enhancement of situation awareness, handling of multifunctional tasks and situation–dependent balancing of workload for the sake of work process productivity (process / cost effectiveness and safety) may become possible.

Cognitive automation has been pushed since some time and appears to be a more and more viable means to ensure that human process control and automation remain compatible concepts. New developments, already tested in field tests, give ample indication that information technology leads the way how to design the cognitive process which is capable to work in a manner as needed for cognitive cooperation. The prototype of CAMA is one example.

## References

Baberg, T. W. (2000): Man–Machine–Interface in modern Transport Systems from an Aviation Perspective. 4th IEEE / IFP International Conference BASYS 2000, Berlin

Bainbridge, L. (1987): Ironies of Automation.
In: New Technology and Human Error, Ed. Rasmussen, Duncan, Leplat, Wiley

Billings, C. E. (1997): Aviation Automation – the search for for a human centered approach. Erlbaum, Mahwah, NJ

Borys, B.–B.; Gudehus, T. C. (2000): Supporting Co–operative Work in Apron Control and Resource Management Offices on Airports. EAM 2000, the 19th European Annual Conference on Human Decision Making and Manual Control, Ispra, Italy

Champigneux, G. (1995): Development environment for Knowledge–based Systems. Some Examples of Application: The Copilote Electronique Project. AGARD LS 200

Dudek, H.–L. (1990): Wissensbasierte Pilotenunterstützung im Ein–Mann–Cockpit bei Instrumentenflug. Dissertation, Universität der Bundeswehr München, LRT

Fabre, F. (1997): Methods for approval of the interface for new cockpit equipment where there is no certification precent. In: Human Factors for Flight Deck Certification, JAA Human Factors Steering Group, London

Frey, A.; Lenz, A.; Onken, R. (1999): Core Elements of the Cognitive Assistant System CAMA. In NATO RTO System Concepts and Integration Panel Symposium, Florence, Italy

Frey, A.; Lenz, A.; Putzer, H.; Onken, R. (2001): In-Flight Evaluation of CAMA – The Crew Assistant Military Aircraft, DGLR-Jahrestagung, Hamburg, (in press)

Funk, K.; Suroteguh, C.; Wilson, J.; Lyall, B. (1998): Flight Deck Automation and Task Management. IEEE Conference on Systems, Man and Cybernetics, San Diego

v. Garrel, U.; Otto, H.-J.; Onken, R. (2001): Adaptive Modellierung des fertigkeits- und regelbasierten Fahrzeugführungsverhaltens (Adaptive Modeling of the Skill-based and Rule-based Driver Behavior). VDI / SAE / JSAE Conference on Der Fahrer im 21. Jahrhundert, Berlin

Gerlach, M.; Onken, R.; Prevot, T.; Ruckdeschel, W. (1995): The Cockpit Assistant System CASSY – Design and In-Flight Evaluation.
In: Anzai & Ogawa (Eds.), Proceedings of the 6th International Conference on Human-Computer Interaction (HCI 95), Tokyo

Grashey, S. (1999): Ein Klassifikationsansatz zur fertigkeitsbasierten Verhaltensmodellierung beim Autofahren. Dissertation, Universität der Bundeswehr München, LRT

Heßler, C. (1989): Einsatz eines Aufgabenmodells zur Erkennung von Bedienfehlern in der Flugführung. In: Gärtner, K.-P. (Hrsg.): Anwendung wissensbasierter Systeme in der Fahrzeug- und Prozeßführung

Johannsen, G. (1993): Mensch-Maschine-Systeme. Springer, Berlin

Johannsen, G. (1997): Cooperative human-machine interfaces for plant-wide control and communication. In: J. J. Gertler (Ed.): Annual Reviews in Control. Oxford: Pergamon, Elsevier Science

Jürgensohn, T. (1997): Hybride Fahrermodelle. Dissertation, ZMMS Spektrum Band 4

Kopf, M. (1994): Ein Beitrag zur modellbasierten, adaptiven Fahrerunterstützung für das Fahren auf deutschen Autobahnen. Dissertation, Universität der Bundeswehr München, LRT

Krüger, H.-P.; Neukum, A.; Schuller, J. (2000): A Workload Approach to the Evaluation of Vehicle Handling Characteristics. SAE, 2000-01-0170

Lizza, C.S.; Rouse, D.M.; Small, R.L.; Zenyuh, J.P. (1991): Pilot's Associate: An Evolving Philosophy. Proceedings of the 2nd Joint GAF / RAF / USAF Workshop on Human-Electronic Crew Teamwork, Ingolstadt

Onken, R. (1993): Funktionsverteilung Pilot Maschine: Umsetzung von Grundforderungen im Cockpitassistenzsystem CASSY, In DGLR-Tagung des Fachausschusses Anthropotechnik

Onken, R. (1998): Die zwei Gesichter der Automation. In 3rd Workshop Verbundvorhaben Cockpit, University of German Armed Forces, Munich, Institute for System Dynamics and Flight Mechanics, Neubiberg, Germany

Onken, R.; Walsdorf, A. (2000): Assistance Systems for Vehicle Guidance: Cognitive Man-Machine Cooperation. BASYS 2000-4th IFIP / IEEE International Conference on IT for balanced Automation Systems, Berlin

Rasmussen, J. (1983): Skills, rules and knowledge, signals, signs and symbols, and other distinctions in human performance models, In IEEE Transaction on Systems, Man Cybernetics, volume SMC-13, pp. 257-266

Romahn, S.E. (1997): Wissensbasierte Unterstützung bei der Benutzung komplexer technischer Systeme – angewendet auf die Arbeit von Piloten mit dem Flight Management System. Dissertation an der RWTH Aachen

Strohal, M. (1998): Pilotenfehler- und Absichtserkennung als Baustein für ein Cockpitassistenzsystem mittels eines halbautomatischen Verfahrens zur Situationsklassifikation. Dissertation, Universität der Bundeswehr München, LRT

Strohal, M.; Onken, R. (1998): Intent and Error Recognition as part of a Knowledge-Based Cockpit Assistant, In SPIE's Aerosense / Defense Sensing Simulation and Control Symposium, Orlando, Florida, USA, 13.-17. April

Stütz, P.; Onken, R. (1997): Adaptive Pilot Modeling within Cockpit Crew Assistance, In 7th International Conference on Human-Computer Interaction, San Francisco, CA, USA

Sundström, G. A. (1993): User modeling for graphical design in complex dynamic environments: concepts and prototype implementations. International Journal of Man-Machine Studies, Vol. 38, pp. 567-586

Winter, H.; van Hood, R. (eds.) (1995): Knowledge-based Guidance and Control Functions. AR 325, AGARD (Advisory Group for Aerospace Research and Development)

Walsdorf, A., Onken, R. (2000): Cognitive Man-Machine Cooperation: Modeling Operator's General Objectives and ist Role within a Cockpit Assistant System, IEEE International Conference on Systems, Man and Cybernetics, Nashville, USA.

# Human Factors in Modern Technology: The Role of Accident Analysis and Databases

*Pietro Carlo Cacciabue*

## Abstract

This paper focuses on importance of Human Factors in modern technology and on the need of improving safety by recognising the existence of human errors and developing means for their management rather than eradication. In particular, the contribution of databases to error and accident prevention is discussed with reference to recording and retrieving information from data reporting systems.

## Introduction

### Human Factors role in Modern Technology

In the last 30 years, the technology has expanded enormously especially for the scope and efficiency of the operations that can be performed by machines alone, exploiting their imbedded autonomous "decision making" rules and mechanisms. Similarly, the role of human beings has undergone tremendous changes and human operators are mainly supervisors and monitors of procedures carried out automatically, once these have been set up by the operators themselves (Sheridan and Johannsen, 1976; Johannsen, 1992; Sheridan, 1992). In particular, the design of automatic systems and the control of the interaction with human operators have become much more complex. Moreover, the consequences of a "human error" or of a "misunderstanding" between human and automation can be unrecoverable and catastrophic (Nagel, 1988).

Two main factors contribute to this new situation: the *enormously improved reliability of hardware*, and the *extensive use of automation*. In particular, advances in hardware technology have vastly reduced mechanical faults and enabled the management of a plant, even in the presence of system faults and malfunctions. In this way, the contribution of human factors to safety analysis has been enhanced and human error has become the primary "cause" of most accidents. However, nowadays automation controls plants and systems of various levels of complexity. Human–centred design principles are utilised to varying degrees of accuracy by manufacturers when designing control systems and interfaces. These principles aim at maintaining a central role for the operator in the management (supervisory) control loop and require that operators are constantly "ahead" of plant's performance, controlling and supervising the automatic system in all its functions and procedures (Johannsen, 1992; Billings, 1997). However, designers do not always respect this fundamental requirement.

Carlo Cacciabue is head of the Human Factors Sector of the Institute for Protection and Security of the Citizen in the EC Joint Research Centre, Ispra, Italy. His activities include accident investigation, design of interfaces and procedures, safety assessment, and training.

Systems behave and respond via the automation, which follow the rules and principles provided by their designers and these are not always totally known or familiar to front-line operators. Moreover, in accidental conditions, the dynamic characteristics of the sequence of events add to the inherent complexity of the situation and further complicate the decision making process If the expected response does not occur, a mismatch occurs between the operator's situation awareness and the automatic system (Bainbridge, 1983). Thus, the working environments are much more demanding in terms of cognitive and reasoning abilities than simple sensory-motor skills (Rankin, and Krichbaum, 1998; Hollnagel, 1993). In summary, while automation reduces and can successfully control most human errors at behavioural-activity level, it increases the impact of consequences of "errors" of reasoning or cognition, as these are deeply rooted into the socio-technical context, and become very difficult to contain.

Current statistics show that accidents in technological environments are very rare, but, in many circumstances, catastrophic events with considerable human contribution to their evolution and scenario. Further reduction of these accidents is seldom possible and usually very expensive. What is preferable is the development of means and techniques that recognise the existence and possible occurrence of human errors, and aim at supporting the management of such errors by offering ways to:

- *Prevent* them and detect them at early stages;
- *Recover* the system performance early after their occurrence; and
- *Contain* them by minimising the consequences in terms of protection for people and environment.

This goal can be achieved by focusing on human-machine interaction issues during four main phases of development of a system, namely (Table 1):

1. the *design* of interfaces and procedures;
2. the *training* of operators for plant management in normal and emergency conditions;
3. the *safety assessment* of the socio-technical system and organisation; and
4. the *accident / incident analyses* of real occurrences for generating data and insight.

The consideration of Human–Machine Interactions (HMI), or human interactions, during the *design* process implies the conservation of the basic principles of human–centred automation. Improving *training* aims at increasing the ability of operators to capture and notice those factors and indicators of the context that favour the occurrence of errors or mismatches between human situational awareness and automation performance. Implementing an accurate *safety assessment* of a system and an organisation represents a basic requirement for evaluating the soundness of a design and for preventing possible accidents. The performance of accurate *accident / incident analyses* is the way in which new risk sources and indicators can be identified and discovered, as consequence of changing contexts and working–environments.

| **Phases of system development** | **Type of Assessment** |
|---|---|
| ***Design*** | • Development of Normal and Emergency Procedures<br>• Design of human-machine interfaces |
| ***Training*** | • Theoretical Human Factors training (non-technical training)<br>• Plant management in normal and emergency |
| ***Safety Assessment*** | • Human contribution to Design Basis Accident (DBA)<br>• Human contribution to Risk Assessment (QRA/PSA)<br>• Regular Safety Audit (RSA) |
| ***Accident Analysis*** | • Human contribution to Accident aetiology (insight on accidents)<br>• Data for design, safety assessment and training |

*Table 1: Application and Basic Requirments for HEM*

A process that may be considered as integral part of safety assessment and combines all elements of all lines of analysis is what may be called *Regular Safety Audits of Organisations (RSA)*. A *RSA* of an organisation consists of the development and recursive application an appropriate and specific method for the evaluation of the safety level of an organisation. By such an approach it is possible to achieve safe and efficient management of a complex system and to identify quite early the degradation of the safety level and therefore to prevent the likely occurrence of accidents.

In order to develop and make operational these lines of error prevention, recovery and control, the effort of several disciplines must be combined, such as engineering know–how, psychology and sociology principles, fundamentals of information technology, practical skill in normal and emergency operations and acquaintance with real system behaviour. In such scenario, it is quite obvious that the design and assessment of safe and effective technology assets is no longer the sole responsibility of engineers, but implies the consideration of different perspectives and the contribution of a variety of specialists, especially from the human related sciences.

## Human Error Management for Safety Improvement

The above discussion lies on the principle that human error can not be completely eliminated and should be considered as an integral part of the life of a system. Therefore, it is essential that appropriate means are devised during all phases of a system development that support *prevention* and *recovery* and *containment* of errors and their consequences. This is the essential contribution of Human Error Management (HEM) to ensure and improve system safety.

Considering the means provided by current technology to HEM for the different phases of development of a system (Table 2), it can be said that *alarms*, *emergency* and *protection* devices represent a well established set of support systems that are universally utilised for preventing accidents and managing inconveniences. The design of this type of systems and associated interfaces is a major endeavour and requires continuous update in order to keep pace with the advances of control systems technology and techniques (Johannsen, 1995, 1997).

*Table 2: Means for Human Error Management*

| HEM / Phase of development | *Prevention* | *Recovery* | *Containment* |
|---|---|---|---|
| ***Design*** | Alarms | Emergency Systems | Protection Systems |
| ***Training*** | CRM | Technical Training | CRM, Tech. Train. |
| ***Safety Assessment*** | QRA/PSA/RSA | - | - |
| ***Accident Analysis*** | Databases | - | - |

The need to expand *training* of plant operators to cover "non–technical" issues, such as team–work, leadership, stress management, communication etc., has been only recently accepted as integral part of the processes for improving safety and reducing human errors. In particular, the development of Crew (or Cockpit) Resource Management (CRM) courses is nowadays included in the formal training practice of pilots and operators of aviation systems (maintenance, cabin assistants, air traffic management) (Wiener et al., 1993). In this way, by technical and non–technical training it is possible to offer a valid support to operators in managing accidents and their own inappropriate behaviour.

*Safety assessments* are mostly focused on the prevention of accidents, even if the evaluation of the risk associated with an accident implies the consideration for many different aspects including the possibility of recovery and containment of consequences. Safety assessment approaches are well–established techniques and represent integral part of the development of any plant and technical system (DOD, 1984). Regular, or Recurrent, Safety Audits (RSA) are more recent methodologies and cover all aspects of accident scenario, even if they are basically oriented to the prevention aspects.

The role of human errors in *accident analysis* is also essential for understanding the causes, defining the evolution of events and for identifying possible means of early detection and prevention of future similar occurrences. An accident investigation strongly depends on the methodological approach adopted by the analysts and usually it results in a very extended report containing a list of critical "findings" and root causes. These are then condensed in a database for statistical assessment and for future uses. Such databases are structured according to taxonomies that should reflect the theoretical grounds, i.e., the methods, on which investigations are based. Moreover, they are very simplified and codified descriptions of the basic findings of investigations. In principle, an accident database should contain the essence of each accident and should allow the reconstruction of basic events and causes by combining the different itemised elements.

In the remainder of this paper we will concentrate on the contribution of databases to error and accident prevention and, in particular, on the recording and recollection processes of information from data collection and reporting systems.

## Human Factors Role in Accident Databases

### Human Models and Taxonomies

The way to analyse the sequence of events and to structure findings into a set of data is a key issue of accident investigation. The definition or selection of a formal method for the evaluation of the causes of an accident is crucial for the organisation and evaluation of factual information. Equally important is the definition of a set of keywords, or taxonomy, that reflect the essence of the adopted theoretical method and allow the structuring of collected information into a database. The richness of information contained in a database and the depth of findings from an investigation depend on the quality and completeness of the adopted method and associated taxonomy.

In the case of human errors, the problem is thus the availability of an adequate model of Human–Machine Interaction and associated taxonomy for classifying human erroneous behaviour. In the context of modern human–machine systems, modelling human behaviour entails considering primarily cognitive processes and system dynamic evolution, i.e., mental activities, resulting from the time dependent interaction of humans and machines. The demand to focus on mental processes and the development of computer technologies generated, in the early 70s, the metaphor of the operator as *Information Processing System (IPS)* and the first formulations of theoretical models of cognition (Neisser, 1967; Newell and Simon, 1972). A variety of paradigms of human behaviour have been developed, inspired by the IPS metaphor (Johannsen and Rouse, 1979; Rouse, 1980; Stassen, et al., 1990; Sheridan, 1992; Rasmussen, 1986). In more recent studies, the focus of research on individual performance has broaden to include also the socio–technical environment affecting behaviour, especially including the management and organisational issues (Reason, 1990, 1997; Edwards, 1972, 1988).

Several taxonomies have been developed in correspondence with human behaviour models. In particular, some taxonomies focus on the cognitive functions and processes that characterise the behaviour of the human being, and thus account for the detailed, or "microscopic", levels of the HMI. Other taxonomies, instead, reflect a more global representation of human interaction with the environment, and can be said to describe the "macroscopic" level of HMI relations. By both these types of taxonomies it is possible to explain causal and logical links between individual behaviour and errors and the underlying factors and contextual circumstances that lie at the core and are the primary causes of unwanted events and accidents.

## Microscopic Type Taxonomy

A typical microscopic type taxonomy is based on an *IPS* model of human behaviour that considers four main *cognitive functions* as basic stages to describe mental and behavioural performance and certain critical *cognitive processes* that govern the four cognitive functions (for example see Rasmussen et al., 1990, or Hollnagel, 1998). The cognitive functions are *Perception*, *Interpretation*, *Planning* and *Execution*, and the cognitive processes focus on *Memory / Knowledge Base* and *Allocation of Resources*. These functions and processes are not chosen at random, but they reflect the consensus on the characteristics of human cognition that has developed over many years (Sheridan and Ferrell, 1974; Pew and Baron, 1983; Johannsen and Rouse, 1983; Sheridan, 1985; Hollnagel, 1993).

A taxonomy based on an IPS model supports the evaluation of the cognitive functions and contextual conditions that have lead to the manifestation of behaviour and errors. For instance, the erroneous operation of a control may be due to an incorrect *interpretation* of the information perceived by the operator. By microscopic type taxonomy this can be logically identified. The fundamental characteristic of the approach requires a formal procedure by which the model and taxonomy are applied for the construction of sequences, carefully linking causes, effects and manifestations of behaviour in a circular dynamic interaction.

Starting from some erroneous manifestation (cognitive function *Execution*), it is possible to search for "generic causes" and "specific causes" that triggered the error of execution, at the immediately higher level of cognitive functions, i.e., *Planning* (Figure 1). Generic causes consist of a list of causes related to the cognitive function immediately linked to the function under analysis, while "specific causes" are essentially made of the environmental and contextual factors that may affect behaviour. This process of identification of causes / effects carries on from Planning to Interpretation and continues until only specific causes are identified as explanation of an erroneous performance.

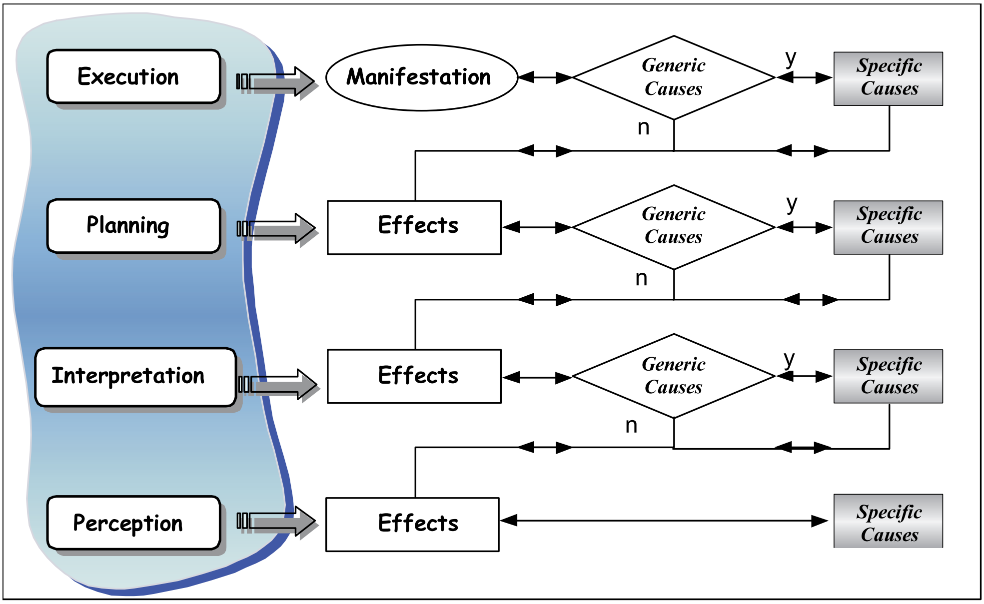



*Figure 1: Application of a microscopic type taxonomy*

As an example, an erroneous manoeuvre may be the result of some specific cause appearing during the execution of the manoeuvre itself, or may be the result of an inappropriate performance of one of the cognitive functions associated with the decision process (planning, interpretation or perception of information) leading to the execution of the manoeuvre.

This process that is applied in a retrospective analysis for the recognition of root causes of erroneous behaviour, may be utilised in the reverse order to support prospective studies for the evaluation of possible manifestation of errors resulting from certain contextual and external factors and inappropriate performance of cognitive functions.

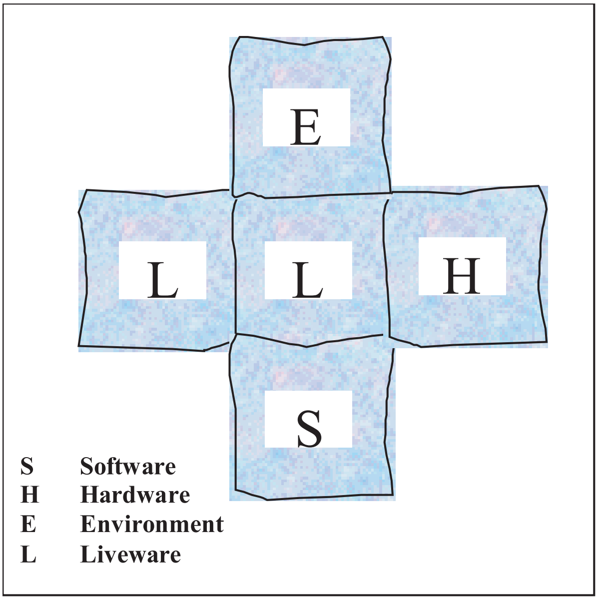
From this short description, it clearly appears how the application of a microscopic type taxonomy focuses on the detail processes that lead to erroneous behaviour and allows the identification of specific environmental and contextual conditions that generated the error. It requires a very precise identification of the dynamic interaction between human and machine and can be applied when specific individual factors need to be analysed or defined.

On the other hand, it becomes very difficult to apply the method to a whole accidental sequence, during which several events and episodes usually combine to generate the whole sequence. Therefore, for the analysis of the sequence of events occurring during an accident, it is necessary to apply a different methodological approach, that reduces precision but favours the assessment of the accident from a wider perspective.

### Macroscopic Type Taxonomy

In macroscopic type taxonomies, the human behaviour is framed within the realm of relations and dependencies that exist between an individual and the surrounding socio-technical context. In particular, the links existing between persons, organisations and society are of particular interest to the analysis of accidents, especially in recent years. A model of human and environment that captures both individual characteristics and their effects on behaviour, as well as organisational and contextual factors, has been developed as an expansion of a previous model, and is called SHELL (Figure 2) (Edwards, 1988; Hawkins 1993).

*Figure 2: The SHELL model for macroscopic type taxonomies*



In this model the human being (*Liveware*, *L*) plays a central role in a system made of other humans (*L*), environment (*E*), hardware (*H*), and software (*S*). *Liveware* represents the human beings in the immediate contact with the central person under analysis. *Environment* consists of external and internal aspects affecting work, including physical characteristics of workplace and social factors such as the management, national and organisational culture. *Hardware* is made of the machinery and equipment, such as controls and interfaces. *Software* represents documentation, procedures, symbols and training affecting human behaviour.

In this way, the central role of the human with the respect to the other components is preserved, and the influence of the socio-technical environment on human behaviour is given particular emphasis. The macroscopic type taxonomy that can be developed from the SHELL model is able to capture the most recent theories of human-machine interaction and root cause analysis, that focus on the role played by the context and organisational issue on human erroneous behaviour (Reason, 1997).

In aviation, for example, a taxonomy specifically dedicated to this domain, called ADREP-2000, has been developed by the International Civil Aviation Organisation (ICAO, 1997) and will be the reference system for collecting data about accidents and serious incidents in the forthcoming years. In the next section, the correspondence of the ADREP-2000 system with theories of organisational factors will be discussed.

## Insight on Human Factors from Accident Databases

In the domain of aviation, the ADREP-2000 data collection scheme of ICAO follows its predecessor in many respects, except for the human factors part, which has been totally revised, primarily for its theoretical background, which is based on the SHELL model. ADREP registers all factors and findings, identified in the investigation according to "*events*" structured in a temporal sequence. Most accidents consist of several inter-related *events*, each one characterised by a "*phase*", indicating the stage of flight. For each event, a free number of "*descriptive factors*" can be identified, and, to explain *descriptive factors*, a number of "*explanatory factors*" can be inserted (Figure 3). Descriptive factors should tell what happened during an event by listing all phenomena. Human actions can in some cases represent a descriptive factor. Explanatory factors give details on *why* the event happened, only when human performances or causes can be associated with the event. A detailed taxonomy has been developed for the definition of the items of ADREP-2000, with reference to the model SHELL.

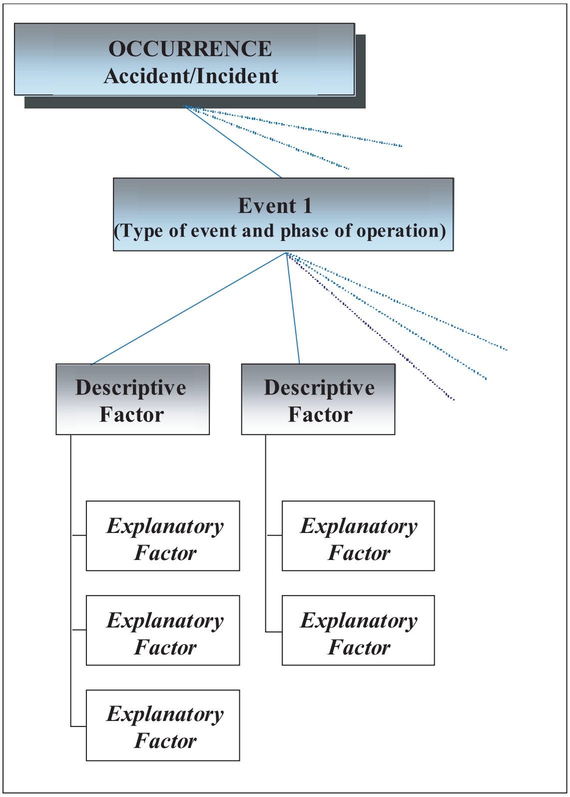


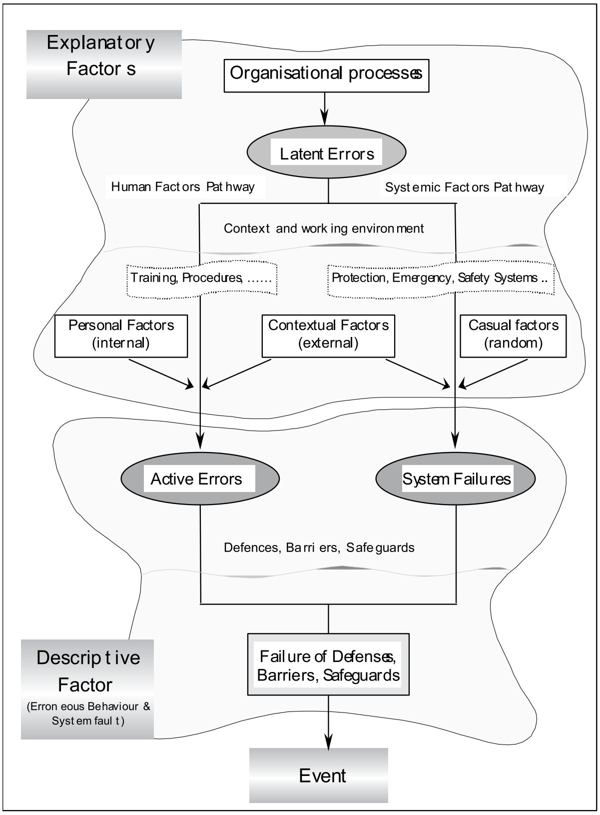

*Figure 3: General structure of ADREP–2000*

The process of classifying an accident according to the SHELL / ADREP–2000 model / taxonomy allows to classify actual manifestations of errors made by humans while performing their tasks. This may be done in consideration for contextual and organisational factors affecting errors, and, considering the temporal sequence of events, which is essential for a deep understanding of the accident evolution. In this respect, ADREP–2000 should be able to reflect the combination of causal links depicted in modern theories of root cause analysis that looks into the whole organisational structure, such as Reason's paradigms of organisational related errors (Reason, 1990, 1997; Maurino et al., 1995).

In short terms, Reason's approach for accident causation correlates human manifestations of errors (*active failures*) to a possible adverse contextual conditions, to personal factors, and / or to a variety of "latent conditions". The latter (*latent conditions / errors*) can correspond to inadequate or erroneous practices, procedures, policies, and philosophies existing within a company, or to errors made in other circumstances, such as at design and maintenance level. This theory can be expanded so as to associate latent errors with system / hardware failures, in addition to human active errors (Caprignano and Piccini, 1999). When focusing on the actual error manifestation the theory can refer to a detailed model of cognitive behaviour in order to catch the psycho–physical factors affecting overt behaviour.

Figure 4 shows the structure of the accident causation model based on the theory of latent / active failures of Reason, which has been overlapped with the structure of ADREP–2000 / SHELL model, showing where and how the two frameworks meet. In particular, the definition of *Event* is common to both approaches and represents the actual circumstance that has resulted from a combination of several human and systemic factors. An accident is made of a (temporal) sequence of *events* ("event time line"). "Active Errors" and "System Failures", in Reason's accident causation framework, correspond to "Descriptive Factors" of ADREP–2000, as they represent what has happened that led to the event and it is usually represented in terms of "failure of certain defences, barriers and safeguards". The rest of the accident causation framework, i.e., active / latent failure structure and associated factors affecting human errors and system failures are well captured by the model and taxonomy of ADREP–2000.

*Figure 4: Accident Causation Model*



In more detail:

- "Personal Factors" are characterised in the taxonomy of ADREP–2000 by a complete set of items referring to "Physical", Physiological", and Psychological" conditions and to "Workload management";
- "Contextual Factors" and "Casual Factors" and the association with latent failures can be found in ADREP–2000 taxonomy at level of L–H, L–E, L–S and L–L interactions. In particular:
  - The L–H makes reference to design errors as well as inappropriate / poor / missing operational material that may generate System Failures or Human Active Errors;
  - The L–E part considers inadequate and unhealthy working environment, as well as lack of regulations, bad management and organisational effects;
  - The L–S items account for insufficient or inappropriate training and procedures;
  - Finally, the L–L section represents problems derived from the interaction of different actors during the performance of the same task, and issues related to teamwork.

The ADREP–2000 taxonomy as been developed at a very fine level of detail. It attempts to reach high precision in the definition of causal factors of human errors, as it identifies the cognitive functions that have failed during the HMIs and associates to them also the organisational and latent aspects that may have influenced active errors. In this sense, it attempts to combine a microscopic and macroscopic type of taxonomy.

The evaluation of completeness and accuracy of information contained in ADREP–2000 has been carried out by performing the study and classification of a number of accidents (Perassi and Cacciabue, 1998). Nine major aviation accidents were analysed and the results of this study, with respect to the assessment of ADREP–2000, can be summarised as follows:

- ADREP–2000 is able to capture human factors aspects much better than the previous classification scheme. Moreover, it matches very well other theories of HMI and enables to identify errors or deficiencies at cognitive level.
- The classification process with ADREP–2000 remains quite complex and cumbersome to complete, especially for the part relative to *explanatory factors*, even for a human factors specialist. For this reason there is a very significant need to develop support tools that would provide appropriate guidance in the application of the taxonomy.
- The contribution of ADREP–2000 to provide data for risk assessment and design of safety management systems in terms of probabilities or failure rates is very limited due to the fact that the data contained are too scarce and dispersed to offer a real contribution.

Indeed, accidents in the domain of aviation are very rare and by a database on accidents alone it is not possible to identify real indicators of incipient failures of defences or conditions of latent errors. Other data, for instance from voluntary reporting systems on near-misses and incidents, are much more appropriate for this purpose, as they are richer in information content, as long as the collected information is properly analysed.

## Conclusions

This paper has tackled the issue of Human Factors contribution to the development of technological systems and it has been proposed to consider human errors as part of the system, which need to be managed by prevention, recovery and containment of consequences.

These three lines of intervention have to be tackled at level of design, training, safety assessment and accident investigation. The latter has been considered in detail, by analysing effectiveness, accuracy and degree of applicability of information contained in the ICAO database system for mandatory accidents.

ADREP-2000, although able to describe the accident from an organisational and socio-technical point of view, was shown to be largely insufficient to offer in-depth insight. It does not offer a solid base for definition of “indicators” of safety state within an organisation, and is not able to provide a consolidated set of data for risk assessment. This is mainly due to the scarcity of the data that can be collected focusing only on mandatory reporting events, while the of theoretical approach was shown to be in line with most recent approaches of human factors analysis.

The exploitation of other sources of investigation and information, such as voluntary reporting, task analysis and, specially, regular assessment of work and safety practices, is suggested as a promising way to obtain real and more effective information and insight about human factors contribution to safety.

## References

Bainbridge, L. (1983): The ironies of automation. Automatica, 19, 6, pp. 775–780

Billings, C. E. (1997): Aviation Automation: The Search for a Human-Centered Approach. Lawrence Erlbaum Associates, Mahwah, New Jersey

Carpignano, A., and Piccini, M. (1999): Cognitive Theories and Engineering Approaches for Safety Assessment and Design of Automated Systems: a Case Study of a Power Plant. International Journal of Cognition Technology and Work, IJ-CTW, 1 (1), Springer-Verlag, London

Edwards, E. (1972): Man and machine: Systems for safety. In Proceedings of British Airline Pilots Association Technical Symposium. British Airline Pilots Association, London, pp. 21–36

Edwards, E. (1988): Introductory overview. In E. L. Wiener, and D. C. Nagel (Eds.), Human Factors in Aviation, Academic Press, San Diego, CA, pp. 3–25

DoD, Department of Defence (1984): System safety program requirements. MIL-STD-882B, DoD, Washington DC

Hollnagel, E. (1993): Human Reliability Analysis: Context and Control. Academic Press, London

Hollnagel, E. (1998): Cognitive Reliability and Error Analysis Method. Elsevier, London

Hollnagel, E., and Cacciabue, P. C. (1991): Cognitive Modelling in System Simulation. Proceedings of Third European Conference on Cognitive Science Approaches to Process Control, Cardiff, UK, September 2–6

Hawkins, F. H. (1993): Human Factors in Flight, Ashgate

ICAO (1997): Accident / Incident Reporting Manual–ADREP 2000 draft (1997). ICAO

Johannsen, G. (1992): Towards a new quality of automation in complex man-machine systems. Automatica, Vol. 28, pp. 355–373

Johannsen, G. (1995): Computer-supported human-machine interfaces. Journal of the Society of Instrument and Control Engineers (SICE) of Japan, Vol. 34, pp. 213–220

Johannsen, G. (1997): Conceptual design of multi-human machine interfaces. Control Engineering Practice, Vol. 5, No. 3, pp. 349–361

Johannsen, G. and Rouse, W. B. (1979): Mathematical concepts for modeling human behavior in complex man-machine systems. Human Factors, Vol. 21, pp. 733–747

Johannsen, G. and Rouse, W. B. (1983): Studies of planning behavior of aircraft pilots in normal, abnormal, and emergency situations. IEEE Trans. Systems, Man, Cybernetics, Vol. SMC-13, pp. 267–278

Maurino, D. E., Reason, J., Johnston, N., and Lee, R. B. (1995): Beyond Aviation Human Factors. Avebury Aviation. Aldershot, UK

Nagel, D. C. (1988): Human Error in Aviation Operations. In E. L. Wiener and D. C. Nagel (Eds.), Human Factors in Aviation. Academic Press, San Diego, CA, pp. 263–303

Neisser, U. (1967): Cognitive Psychology. Appleton-Century-Crofts, New York

Newell, A., and Simon, H. A. (1972): Human Problem Solving. Prentice-Hall, Englewood Cliffs, N.Y.

Pew, R. W., and Baron, S. (1983): Perspectives on Performance Modelling. Automatica, 19, No. 6, pp. 663–676

Perassi, A., and Cacciabue, P. C. (1998): Human Factors insight in databases of aviation accidents: comparing past and present classification schemes. Proceedings of 17th European Annual Conference on Human Decision Making and Manual Control. Valenciennes, France – December 14–16, 1998

Rankin, W., and Krichbaum, L. (1998): Human Factors in Aircraft Maintenance. Integration of Recent HRA Developments with Applications to Maintenance in Aircraft and Nuclear Settings. June 8–10, 1998, Seattle, Washington, U.S.A.

Rasmussen, J. (1986): Information processes and human–machine interaction. An approach to cognitive engineering. North Holland, Oxford

Rasmussen, J., Pejtersen, A. M., and Schmidt, K. (1990): Taxonomy for cognitive work analysis. In J. Rasmussen, B. Brehmer, M. de Montmollin, and J. Leplat (Eds.) Proceedings of the 1st MOHAWC Workshop, Liege, 15.–16. May, Vol. 1 ESPRIT Basic Research Project 3105, European Commission, Brussels, Belgium, pp. 1–153

Reason, J. (1990): Human Error. Cambridge University Press, Cambridge, UK

Reason, J. (1997): Managing the risks of organisational accidents. Ashgate, Aldershot, UK

Rouse, W. B. (1980): Systems Engineering Models of Human–Machine Interaction, North Holland, Oxford

Sheridan, T. B. (1985): Forty–five years of Man–Machine systems: history and trends. Keynote Address. Proceedings of 2nd IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design and Evaluation of Man–Machine, Varese, Italy, 10.–12. September. pp. 5–13

Sheridan, T. B. (1992): Telerobotics, Automation and Human Supervisory Control. The MIT Press, Cambridge, MA

Sheridan, T. B., and Ferrell, W. R. (1974): Man–Machine Systems: Information, Control and Decision Models of Human Performance. MIT Press, Cambridge, MA

Sheridan, T. B. and Johannsen, G., (Eds.) (1976): Monitoring Behavior and Supervisory Control. Plenum Press, New York

Stassen, H. G., Johannsen, G. and Moray, N. (1990): Internal representation, internal model, human performance model and mental workload. Automatica, 26 (4), pp. 811–820

Wiener, E. L., Kanki, B. G. and, Helmreich, R. L., (Eds) (1993): Cockpit Resource Management. Academic Press, San Diego, CA

# Supervisory Control and Decision Making

*Toshiyuki Inagaki*

Toshi Inagaki received his doctoral degree in systems engineering from Kyoto University in 1979. From 1979 to 1980 he was a Research Associate at the University of Houston. Since 1980 he has been with the University of Tsukuba, where he is a Professor at the Institute of Information Sciences and Electronics. From 1990 to 1991 he held Research Fellowship of the Alexander von Humboldt Foundation, and did a research on human supervisory control at the Laboratory of Prof. Gunnar Johannsen, University of Kassel. Since 1996, Inagaki has been Leader of a research project on human-centered automation at the Center for Tsukuba Advanced Research Alliance, University of Tsukuba. Dr. Johannsen was a member of the project during the first three-year period. Research interests of Inagaki include dynamic function allocation, reliability and safety of human-machine systems, human trust in and distrust of automation, mathematical and experimental evaluation of human interface, reasoning and decision making with imprecise information.

## Abstract

This paper discusses how human decisions can be normative or recognition-primed under time-criticality in human supervisory control. Necessity of a careful investigation on the continuum of decision problems is suggested to clarify what kind of decision aid or training should be given to human operators and when. This paper also argues the need for dynamic trading of decision authority between human and automation for assuring safety of human-machine systems. It is not always appropriate to assume that "human must have the final authority over the automation" at all times and on every occasion.

## Introduction

Human supervisory control is a model to represent human-computer interaction in semi-autonomous systems where computers control the process according to directives given by a human operator (Sheridan and Johannsen, 1976; Sheridan, 1992). The human operator plans what task to do and how to do it, gives the computer directives to execute the plan, monitors the computer's automatic action, and interrupts the automatic control, when necessary, to specify a new goal state. Decision-making is thus required at various phases in human supervisory control.

Theory of decision-making has been one of main research issues in systems engineering. A conventional decision theory assumes that a decision-maker generates an exhaustive set of decision alternatives, evaluates every alternative, and then picks up the alternative with the maximum benefit (or minimum cost). These models discuss *"what people ideally could do"* or *"what real people should do"* (Sage, 1992), and are called normative decision models.

*Descriptive decision models*, on the other hand, try to describe, "what people do" and are *"concerned with the way in which human beings in real situations actually make decisions"* (Sage, 1992). *Naturalistic Decision Making* (NDM) research is one of such approaches and has been gaining much attention (Klein, Orasanu, Calderwood, and Zsambok, 1993; Zsambok, 1997; Klein, 1998). NDM researchers say that normative decision models do not represent well expert decisions in natural environments. *Recognition-primed decision* (RPD) model has been proposed to describe an expert decision making in dynamic, time-compressed settings in which diagnosing a situation plays much more an important role than selecting a course of action (Klein, 1998).

This paper argues that normative and recognition-primed decision frameworks are not necessarily mutually exclusive. Suppose a decision problem must be solved in a specific context in human supervisory control. The problem can be recognition-primed under a certain set of parameter values, and can be normative when some other set of parameter values is given. Investigation is necessary to clarify when and where a normative decision theory is needed and in which circumstances a recognition-primed decision-making becomes more appropriate. A continuum of decision problems is suggested for such a parametric investigation.

An issue of decision authority is also significant in the research of human-machine systems. It is often said that, *"the human must be at the locus of control"*, or, *"the human must be maintained as the final authority over the automation"* (Woods, 1989; Billings, 1997). These statements are sensible and reasonable, because it is not realistic to assume that machine intelligence is perfect, although it is often highly capable. However, it may be too strong to claim that, "human must be maintained as the final authority over the automation *at all times and on every occasion*." Operating environments change with time, and it may not be easy for humans to make a correct decision in a highly dynamic environment, especially when available time or information is limited. This paper argues that the final authority for decision and action may be traded flexibly and dynamically between humans and automation, and that there can be cases in which automation may be given the final authority for ensuring the safety of a system.

## Decision Making Problems

The following is a conventional mathematical programming formulation for a normative decision-making.

(MP) minimize $f(x)$

subject to $x \in D$

where it is requested to find an "optimal" decision $x$ that minimizes the objective function $f(x)$. In the above model $f(x)$ may represent the cost (or, the expected cost for cases of decision making under uncertainty). Every option $x$ in the set $D$ of feasible solutions is evaluated in terms of $f(x)$, explicitly or implicitly, and they are compared with each other to seek for an optimal solution. It is easily seen that the model (MP) is suitable for investigating what a "rational" decision-maker should do.

Researchers of naturalistic decision making say that how people actually make decisions differ from what the normative decision model (MP) represents. For instance, Orasanu and Connolly (1993) claim that the NDM models differ from normative ones in at least the following points:

1. Much effort is devoted to situation assessment or figuring out the nature of the problem.
2. Single options are evaluated sequentially through mental simulation of outcomes.
3. Options are accepted if they are satisfactory (rather than optimal).

We will see in the next three sections, however, how normative models can be useful under risk and time–criticality. Especially, it is shown that there can be cases in which an expert may have to adopt a normative way of thinking when efforts through 1.–3. in the above could not find a satisfactory option.

## Go / NoGo Decision

Let us take, as an example, a Go / NoGo decision upon an engine failure during a takeoff roll. The standard decision rule for the Go / NoGo decision making is stated as follows:

(i) If the aircraft speed is below V1, then reject the takeoff, and

(ii) if V1 has already been achieved, then continue the takeoff.

In 14 CFR 25.107, V1 is called the *takeoff decision speed* that is defined as the speed at which the pilot must apply the first retarding means to abort the takeoff (FAA, 1992).

The most important decision for the pilot, when she faces with some abnormality during takeoff role, is a situation–diagnostic decision. Once the situation is diagnosed (say, that an engine is failed and V1 has been already achieved), a course of action decision (to continue the takeoff, or to abort the takeoff) is automatic. The pilot's Go / NoGo decision is thus recognition–primed (Orasanu and Fischer, 1997). However, that does not mean that a normative model is useless for the Go / NoGo decision problem. On the contrary, the normative decision model plays an essential role. It is important to remember how the decision rule for the Go / NoGo problem was developed. The decision rule was established and validated by experts who constitute a team for flight safety, such as engineers in manufacturers or airlines, via a normative theoretic investigation where both action alternatives, "Go" and "NoGo", are evaluated and compared with each other explicitly for every possible situation.

An engine fire in the takeoff phase may make the Go / NoGo decision complicated. If the fire could not be extinguished soon after climbing up to a certain altitude, its associated outcome may be more severe than an overrun due to a NoGo decision after V1. Even though situation–diagnostic decision (i.e., the engine got a fire) is done correctly, a course of action decision might not be automatic or straightforward, and comparison between action alternatives may still be necessary.

Thus it would be possible to say that, although pilots themselves do make their Go / NoGo decisions in a recognition–primed manner, somebody in their team of experts really need a normative investigation to support pilots by letting them have a reasonable decision rule or guideline. Pilots' recognition–primed Go / NoGo decision is a rule–based behavior. As long as pilots make their decisions by following the normatively developed decision rule, we have to respect the value of a normative decision theory.

### Decision With Uncertain Alerts

The automated alerts, such as GPWS (Ground Proximity Warning System) and TCAS (Traffic Alert and Collision Avoidance System), are meant to signal real threats or emergencies that demand an immediate response. Due to some causes, alerts may not be trusted blindly. However, a thorough validity analysis of a given alert may not be possible under time–criticality. Thus there can be cases in which a pilot is uncertain whether the alert is correct or not, or in other words, the pilot's situation–diagnostic decision has not been completed. Nevertheless, the pilot has to decide what to do. If this were the case, it would not be possible for the pilot to make her decision in a purely recognition–primed manner.

Consider a case in which a GPWS warning sounds, "Pull–up, Pull–up, Pull–up" when an aircraft is making a final approach. Suppose the Pilot–Flying (PF) is not very sure whether the warning is correct. Suppose the warning was correct. If the PF decided to disregard the warning, then a CFIT accident may occur. Suppose, on the other hand, the warning was false. If the PF took a pull–up maneuver, then she would realize some time later that the go–around was unnecessary. An important point to note is that, once an action was taken, no "undo" might be allowed. Even when situation–diagnosis has not been completed, the PF must take some "appropriate" action. To do so, she needs to compare two possible action alternatives, to pull–up or not, which is a normative way of thinking. Or, as discussed earlier, a normative analysis needs to be done in advance by some team members on the ground to develop a decision rule.

Inagaki and Parasuraman (2000) have proven that a course of action decision for TCAS may be harder than that for GPWS. Suppose that the TCAS gives a resolution advisory (RA), "Climb, Climb, Climb," and that the PF failed to judge whether the RA is correct or not. If the RA was correct and if the PF disregarded it, a collision against an intruder's aircraft may occur. If the PF made a climb due to a false RA, her aircraft would deviate from an original flight path, which might produce a new threat of collision with other aircraft or cause inconvenience in continuing its flight. No recognition–primed decision is possible in this circumstance, because a situation–diagnostic decision is not fully completed and *Level 2 situation awareness* (Endsley, 1995) is not attained properly.

A normative model does not always give a definite answer to whether to climb or not, when a pilot was not sure of a given RA to climb. Inagaki and Parasuraman (2000) have shown that the "best" policy varies depending on situational parameters, such as reliability of TCAS, possibility of encountering aircraft other than the original intruder aircraft, cost associated with improper decision or delayed action. Parametric investigations based on a normative model would be necessary to develop guidelines for pilot's course of action decisions. It must be noted that thus developed decision guidelines would include some situational parameters that must be evaluated in real time. The pilot's situation-diagnosis finally determines a course of action when she was not very sure of validity of a TCAS alert. This implies, a recognition-primed decision aspect can be found in a normative decision model.

### Where to Divert

Consider the following fictitious situation.

*"While cruising at 35,000 feet, a two-engine passenger aircraft got a trouble on its left engine. The captain recognized that the engine was damaged seriously, and shut it down. The destination, Airport Y, is rather a small provincial airport, reported weather of which at that time moment was not good and is becoming worse. The weather conditions at the planned alternate, Airport Z, are also reported badly. The captain has to pick up a suitable airport to divert as soon as possible."*

In the selection of an airport to divert, the following factors are usually taken into account:

1. Fuel endurance
2. Weather conditions
3. Airport facilities (such as, runway length, ATC facilities, navigation aids, waiting lounge for passengers)
4. Maintenance facilities
5. Passenger handling capability (such as, provision for refreshments, money for refunds, medical facilities, ground transportation)

Once an immediate landing becomes necessary, it is a common practice to pick up the nearest airport as the first candidate. When the first option were judged to be acceptable through mental simulation, the captain usually adopts the option. The second option is generated only if the first option was not acceptable: Options are evaluated sequentially, and are not compared with each other. These are typical characteristics of recognition-primed decisions (Orasanu and Connolly, 1993).

However, the decision process of the captain can be a bit complicated. The following is such a circumstance.

*"The nearest airport is Airport U, located within 30 miles. It has a 3200-meter-long runway, but only a non-precision approach facility is available. The weather conditions are poor; visibility may go below the minimums for landing. The captain is not satisfied with Airport U, and tries to look for a better alternative.*

*The second nearest airport is Airport V, located 50 miles away. The runway of the airport is just 1800-meter long. The weather conditions are reported very well. Airport V has neither a passenger terminal nor maintenance facilities. Moreover, the 1800-meter-long runway is not long enough for a one-engine-inoperative landing. She has to investigate the third option.*

*Airport W, located 100 miles off the airway, is an international airport with a 3500-meter runway, where approach radar, ILS, and a passenger terminal are available. The airport is famous for being very busy. The weather conditions are currently reported bad, "crosswind factor 15 knots, visibility 1/4 mile, ceiling indefinite 200 feet obscured," though gradual recovery is expected. The captain is not very sure of recovery of the weather before they get there. If the weather might be still bad, they would have to divert again to some other airport, which is not feasible, because of fuel endurance. Thus Airport W is not a readily acceptable option.*

*Now the captain notices that there is no more possible option available. Even though the captain cannot be fully satisfied with the three options, U, V, and W, she has to select one of them. The captain thus begins to compare those three options carefully. Since there is no option that is superior to any other in every respect, the captain must investigate tradeoff relationships among option characteristics."*

At the final stage, the captain has the complete set of alternatives {U, V, W} and has to select the "most appropriate" option, where comparison among options are inevitable. This is a normative decision-making. Precisely speaking, the problem is a typical multi-objective programming (MOP) problem, where the decision-maker should pick up the "most appropriate" solution by taking into account tradeoff relationships among objectives. The (MOP) usually seeks for an option that is "good enough" rather than "optimal." This fact suggests that a normative and the recognition-primed decision frameworks are not necessarily mutually exclusive.

## Continuum of Decision Problems

The discussions in the previous three sections suggest the need for a *continuum of decision problems* that ranges from a pure normative decision model to a purely recognition--primed decision model, as depicted in Figure 1. The continuum expresses the following points:

1. Some decision-making problems in human supervisory control exhibit both aspects of normative and recognition-primed.
2. A single decision making problem may change its nature from recognition-primed to normative, and vice versa, as parameters in the problem change their values.

It is thus important to investigate when and how decisions of an operator may change their nature to design an appropriate support.

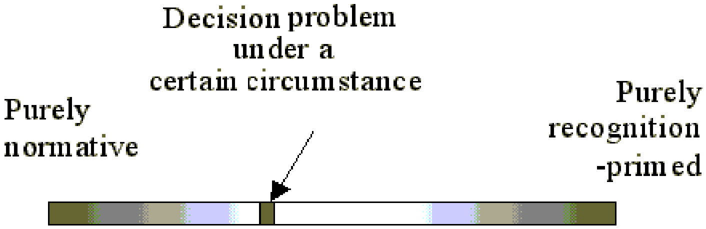



*Figure 1: Continuum of Decision Problems*

## Trading of Decision Authority

In the crash of a Boeing 757 aircraft near Cali in 1995, pilots performed a terrain avoidance maneuver immediately upon a GPWS alert. However they failed to stow the speed brake which they had extended some time before under their previous intention to descend (Dornheim, 1996). The CFIT accident could have been avoided if there had been an automatic mechanism to retract the speed brake if it had not yet been stowed when the maximum thrust was applied. It is highly unlikely to apply the speed brake and maximum thrust at the same time. When automation detects such a contradiction, it seems reasonable to let the automation adjust the configuration automatically so that the new configuration may fit well to the human's latest intention.

A similar discussion may be made regarding the crash of an Airbus 300-600R aircraft at Nagoya in 1994. At some point during the final approach, the pilot flying gave a Go-Around directive to the automation *unintentionally*. The automation started its manoeuvre for going around. However the pilot decided to descend for landing. The pilot knew that the autopilot was in the Go-Around mode, but he did not follow an appropriate procedure to cancel the mode. Once the automation was ordered by the human to go around, it tried to achieve the go-around at any cost. For the automation, the human's input to descend was simply a disturbance that must be cancelled out by applying larger control input. From the viewpoint of the pilot, the aircraft did not descend smoothly and thus he applied larger control input. Thus the aircraft was subject to completely contradictory controls by two agents with opposite intentions. If the automation had been given the right to adjust its goal of action automatically so that the new goal fitted well to the human's latest intention to descend, then the conflict leading to the crash could have been avoided. However, if we assume that final authority may be granted only to humans, then all the automation could do was to stick to its current maneuvering policy since it was not told by the human to forget the earlier directive.

The above discussions lead to the following conclusions. The automation may be given the right to take an automatic action to maintain system safety, even when an explicit directive may not have been given by an operator at that moment, providing the operators have a clear understanding about the circumstances and corresponding actions which will be taken by the automation.

The issue of authority can be discussed in terms of the level of automation (LOA). Table 1 gives the scale of LOA suggested by Sheridan (1992). If it is assumed that the human must be in authority, then LOA must stay within the range of 1 through 5, because the human will not be in full authority with LOA set at 6 or higher. However, we have already seen the need of high LOA for attaining system safety. By using mathematical models, Inagaki (1993, 2000) has shown that final authority may be traded flexibly between human and automation. More precisely, LOA may be altered dynamically depending on the situation encountered, and LOA at level 6 or higher may be adopted when judged to be necessary to attain system safety. Some experiments (Inagaki, Takae, and Moray, 1999; Moray, Inagaki, and Itoh, 2000) have confirmed the efficacy of the *situation-adaptive autonomy* in time-critical conditions.

Dynamic alteration of LOA and its effects have been actively studied by many researchers in adaptive automation (see, Mouloua and Parasuraman, 1994; Parasuraman and Mouloua, 1996; Mouloua and Koonce, 1997; Scerbo and Mouloua, 1999). The trading of authority closely relates to the issue who is given control over invoking automation. See Scerbo (1996) for a thorough review of adaptive automation studies and issues of automation invocation.

*Table 1: Scale of Levels of Automation (Sheridan, 1992)*

1. The computer offers no assistance, human must do it all.
2. The computer offers a complete set of action alternatives, and
3. narrows the selection down to a few, or
4. suggests one, and
5. executes that suggestion if the human approves, or
6. allows the human a restricted time to veto before automatic execution, or
7. executes automatically, then necessarily informs humans, or
8. informs him after execution only if he asks, or
9. informs him after execution if it, the computer, decides to.
10. The computer decides everything and acts autonomously, ignoring the human.

Introduction of automation described above may be controversial. We have learned through past accidents or incidents that automation can bring negative consequences to humans, such as the out-of-the-loop performance problem, loss of situation awareness, automation-induced surprises (see, for example, Sarter and Woods, 1995a, 1995b; Wickens, 1994). From a mathematical point of view, however, there is a rationale for investigation of the trading of decision authority. Suppose we want to maximize system performance, $f(x)$, subject to constraints, where $x$ denotes a decision variable that determines a LOA. Assume $D \supseteq E$. Then it is obvious that,

$$\max\{f(x): x \in E\} \le \max\{f(x): x \in D\}$$

Assuming that, "human must be maintained as the final authority over the automation at all times and on every occasion" gives a stricter constraint than assuming "human and automation may be allowed to trade the final authority depending on the situation." Why do we have to solve the problem under stricter constraints?

Suppose the analysis draws a conclusion that automation must be given the final authority for decision and control under some mathematical condition. If the conclusion was not acceptable, the mathematical condition itself may be analyzed to seek for a way to avoid usage of automation. A typical example of such an analysis can be found in Inagaki (2000) that discusses a rejected takeoff (RTO) problem: A mathematical analysis has proven that the final decision authority must be traded dynamically between humans and automation. A further analysis has shown that, for a human pilot to be given decision authority all the time, human-interface must be changed so that human can be supported Go / NoGo decision directly and explicitly.

## Conclusion

This paper has argued that decision in human supervisory control can either be normative or recognition-primed. To which category a decision problem is classified depends heavily on contexts, dynamic nature of the problem itself, and surrounding environments. Even for a single decision problem, detailed investigation would be needed to clarify when and where a normative decision theory is needed and in which circumstances a naturalistic or a recognition-primed decision-making becomes more appropriate. A close investigation on the continuum of decision problems would be necessary to identify what kind of decision aid or training should be given to human operators and when.

This paper has also discussed the need for situation-adaptive trading of decision authority between human and automation. It is argued that the so-called human-centered automation needs more careful investigation regarding the decision authority. If human was to be the final authority over the automation at all times and on every occasion, safety of the human-machine system might not be assured. Dynamic and flexible trading of authority may be needed especially for human-machine systems in which a non-professional human (who may not always be well trained) serves as an operator.

## References


Billings, C. E. (1997). Aviation Automation – The Search for a Human-Centered Approach. LEA

Dornheim, M. (1996). Recovered FMC memory puts new spin on Cali accident. Aviation Week, September 9, pp. 58–61

Endsley, M. (1995). Towards a Theory of Situation Awareness in Dynamic Systems; Human Factors, 37/1, pp. 32–64

FAA (1992). Takeoff Safety Training Aid.

Inagaki, T. (1993). Situation-adaptive degree of automation for system safety. Proc. 2nd IEEE RO-MAN, pp. 231–236

Inagaki, T. (2000). Situation-adaptive autonomy for time-critical takeoff decisions. International Journal of Modelling and Simulation, 20/2, pp. 175–180

Inagaki, T. and Parasuraman, R. (2000). Probabilistic analysis of human interaction with automated alerts. Proc. 5th Conf. Probabilistic Safety Assessment and Management, pp. 2405–2410

Inagaki, T., Takae, Y., and Moray, N. (1999). Automation and human interface for takeoff safety. Tenth Int. Symposium on Aviation Psychology, Columbus, pp. 402–407

Klein, G. (1998). The Source of Power. MIT Press

Klein, G., Orasanu, J., Calderwood, R., and Zsambok, C. E. (Eds.) (1993). Decision Making in Action: Models and Methods. Ablex

Moray, N., Inagaki, T., & Itoh, M. (2000). Adaptive automation, trust, and self-confidence in fault management of time-critical tasks. Journal of Experimental Psychology: Applied, 6(1), pp. 44–58

Mouloua, M. and Parasuraman, R. (Eds.) (1994). Human Performance in Automated Systems: Current Research and Trends. Erlbaum

Mouloua, M. and Koonce, J. M. (Eds.) (1997). Human-Automation Interaction: Current Research and Practice. Erlbaum

Orasanu, J. and Connolly, T. (1993). The reinvention of decision making. In G. Klein, et al (Eds.), Decision Making in Action: Models and Methods (pp. 3–20). Ablex

Orasanu, J. and Fischer, U. (1997). Finding decisions in naturalistic environments: The view form the cockpit. In C.E. Zsambok & G. Klein (Eds.), Naturalistic Decision Making (pp. 343–357). LEA

Parasuraman, R. and Mouloua, M. (Eds.) (1996). Automation and Human Performance, LEA, pp. 37–63

Sage, A. P. (1992). Systems Engineering. Wiley

Sarter, N. B. and Woods, D. D. (1995a). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. Human Factors, 37(1), pp. 5–19

Sarter, N. B. and Woods, D. D. (1995b). Autonomy, authority, and observability: Properties of advanced automation and their impact on human–machine coordination, Proc. IFAC International Symposium on Man–Machine Systems, pp. 149–152

Scerbo, M. W. (1996). Theoretical perspectives on adaptive automation. In R. Parasuraman and M. Mouloua (Eds.). Automation and Human Performance, LEA, pp. 37–63

Scerbo, M. W. and Mouloua, M. (Eds.) (1999). Automation Technology, and Human Performance: Current Research and Trends. LEA

Sheridan, T. B. (1992). Telerobotics, Automation, and Human Supervisory Control. MIT Press

Sheridan, T. B. and Johannsen, G. (Eds.) (1976). Monitoring Behavior and Supervisory Control. Plenum

Wickens, C. D. (1994). Designing for situation awareness and trust in automation. Proc. IFAC Integrated Systems Engineering, pp. 77–82

Woods, D. D. (1989). The effects of automation on human's role: Experience from non–aviation industries. In S. Norman and H. Orlady (Eds.). Flight Deck Automation: Promises and Realities, NASA CP–10036, pp. 61–85

Zsambok, C. E. (1997). Naturalistic decision making: Where are we now? In C.E. Zsambok & G. Klein (Eds.), Naturalistic Decision Making (pp. 3–16). LEA

# Musings on Music Making and Listening: Supervisory Control and Virtual Reality

*Thomas B. Sheridan*

"Information Theory, Photosynthesis and Religion" was an imaginary title used by the MIT information theorists Peter Elias and David Huffman a half century ago to deprecate efforts to generalize certain mathematical theories to just about everything. Perhaps we are guilty of doing the same, with a symposium tying supervisory control to music. With that precautionary caveat let us consider the topics at hand:

## Music as supervisory control: A three level hierarchy

At first glance the very idea that supervisory control and music have any significant relation one another seems far-fetched. And I have no idea what connection Prof. Dr. Ing. Johannsen has in mind. But upon reconsideration, I find that the connection is quite natural and even rich for consideration.

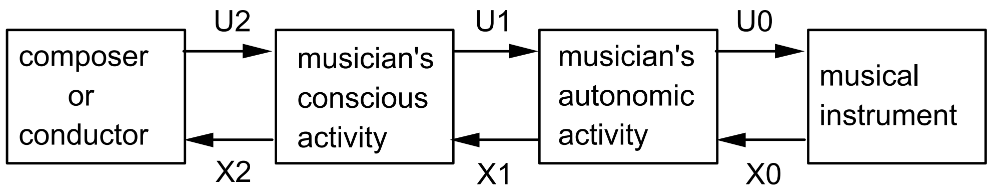
Supervisory control has been defined as the situation where "One or more human operators are intermittently programming and continually receiving information back from a computer that itself closes an autonomous control loop from its sensors and through its actuators to the controlled process or environment.

Let me modify that definition just a tiny bit to make it more general: substitute "information processor, living or artificial" for "computer." Then we can use the notion of supervisory control to characterize a music-making system as:

1. a human, acting as composer, conductor or teacher, "programming" another human to play an instrument, or
2. a human programming his or her own body to play an instrument, where in the latter case the conscious brain programs and exercises a lower-than-conscious semi-automatic nervous system to perform on an instrument,
3. 1. and 2. in combination

Since the combination 3. subsumes 1. and 2. let us consider it in detail. It is depicted in Figure 1. $U_0$, $U_1$ and $U_2$ represent successively higher level command variables, while $X_0$, $X_1$ and $X_2$ represent successively higher state variables (the state of each right-hand element intended to be controlled by the left-hand element.

*Figure 1. The hierarchical cascade of cause-effect relationships in music.*



Thomas B. Sheridan is Ford Professor of Engineering and Applied Psychology Emeritus in the Department of Mechanical Engineering and Department of Aeronautics and Astronautics of the MIT. He has served as a visiting professor at University of California Berkeley, Stanford, Delft (Netherlands), Kassel (Germany, with Prof. Johannsen), and Ben Gurion (Israel). He is co–author of Man–Machine Systems (MIT Press 1974, 1981; USSR, 1981), coeditor (with Prof. Johannsen) of Monitoring Behavior and Supervisory Control (Plenum, 1976), author of Telerobotics, Automation, and Human Supervisory Control (MIT Press, 1992), co–editor of Perspectives on the Human Controller (Erlbaum, 1997) and author of Humans and Automation (forthcoming). He is currently Senior Editor of the MIT Press journal Presence: Teleoperators and Virtual Environments and serves on several editorial boards. He chaired the National Research Council's Committee on Human Factors, and has served as President of the IEEE Systems, Man and Cybernetics Society and Editor of IEEE Transactions on Man–Machine Systems. He was also President and is a Fellow of the Human Factors and Ergonomics Society and an IEEE Fellow. He was elected to the US National Academy of Engineering in 1995. He received several Medals and Awards.

First, what might be gained by considering the relationship in these terms? I believe a greater understanding of what music–making is, at least with respect to communication (between participants and with their instruments), biomechanics (the relations of forces and kinematics of the human body), dynamics (the study of forces and movements of the elements of a system in temporal relation to one another), and control.

## The $0^{th}$ level of control: biomechanics

The $0^{th}$ ($U_0$, $X_0$) level of control is biomechanical. This is the level at which we know the most with respect to manual control. Depending on the instrument the musician must move her fingers, hands and arms and possibly her lips and lungs in programmed patterns. The combined mass, damping and elastic characteristics of these body parts as well as the bow, percussion device, keys (on a piano or wind instrument) etc. constrain the relationship between the driving forces $U_0$ (from muscles) and the body segment displacements $X_0$.

For any physical body in the known universe there is an approximate relation

$$U_0 / X_0 = MD^2 + BD + K \qquad (1)$$

which holds, otherwise known as Newton's law. D in the equation stands for time derivative (or rate), $D^2$ for time second derivative (or acceleration), M for mass, B for viscous damping, and K for stiffness. B and K can be non–linear parameters, so for that reason the (linear) differential equation above is only a first approximation. From this equation we can determine that the natural frequency of a simple spring–mass system with negligible damping is

$$\omega_n = (K / M)^{0.5} \qquad (2)$$

This determines the frequency of a vibrating string or a vibrating column of air in an organ pipe of a woodwind instrument (e.g., a tighter string increases frequency, a longer and heavier string decreases it). As damping, the B in equation (1), increases, the frequency of vibration gets proportionately lower. Equations (1) and (2) also determine the natural rhythm of human body movement, the pace that the body naturally falls into with minimal forcing, and the temporal pattern that requires the least effort to sustain it. In the case of human body limbs we have a rotational spring–mass–damper systems, meaning the mass elements (limbs, head, etc.) are rotating around various joints. But the same rules apply, the muscles serving as both springs and dampers, their coefficient values depending on how loosely or tightly the agonist and antagonist muscle pairs are flexed.

One can freely (with muscles relaxed) wiggle the wrist, wag the head, swing the arm, swing the leg, walk, run, dance and very easily discover these natural frequencies. One finds from experiment that the natural frequency of wrist wiggling is slightly faster than that for arm swinging, because, for fixed K, the distance L from the associated joint to the equivalent mass concentration point is longer (where rotational inertia, the equivalent of M in equation (2), is $ML^2$). One also discovers that the range of natural frequencies is quite small, say between 1 Hz (a slow walk) and 4 Hz (wrist wiggling).

If a limb is hanging vertically and freely (muscles are very relaxed, so that both damping and stiffness of the muscles are near zero) the limb forms a pendulum. In this case the force of gravity provides the more dominant restoring (spring) torque, pushing the pendulum toward its neutral (vertical) position. Since the restoring torque (rotational equivalent of K) is proportional to M and pendulum length L, and the rotational inertia (rotational equivalent to M) = $ML^2$, the natural frequency of the pendulum is proportional to

$$(ML / ML^2)^{0.5} = (1 / L)^{0.5} \qquad (3)$$

This means that the range covering pendular natural frequency of wrist, arm and leg pendula is again quite small, perhaps again only between roughly 1 and 4 Hz.

So is there some significance of this for music? Yes, tremendous significance, in the sense that the biomechanics absolutely constrain the spectrum of rhythmic pattern which we call music. The musician, depending on the instrument, moves his or her limbs, coupled also to the controllable parts of the musical instrument, according to a musical "beat." The frequency range of this "beat" lies in this same narrow range, roughly between 1 and 4 Hz. The pacing is actively controlled by the muscles, where the damping is not so small that the natural limb resonances "fight" the active control – unless the muscles try to drive the limbs faster than approximately 4 Hz. (Note that the range of musical pitches is governed by the organs of hearing, the most sensitive range of the basilar membrane lying between roughly 50 and 5000 Hz, a factor of 100 between lowest and highest frequency. We know that elephants and other large creatures communicate at much lower frequencies, perhaps for some analogous biomechanical reasons.)

Theoretically music could be made at any other range of rhythm or pace, from one "beat" per hour (or some maximum duration of sitting) up to a frequency that becomes a sound rather than a beat. But musicians do not employ these frequencies, for it would not be "natural".

## The 1st level of supervisory control: putting the notes together

Referring back to Figure 1, muscle forces $U_0$ drive $X_0$ into conformance with $U_1$ commands, one note at a time, under the above timing constraints. This servomechanism can be called the lowest level of sensory–motor skill. At this biomechanical level $U_0$ and $X_0$ are essentially below the conscious level, except for the raw beginner instrumentalist.

The $U_1$ pattern is the output of a mostly conscious higher level process which has $X_1$, the musician's hearing, as its feedback. What is heard is the guide to what is next ordered by the brain in the form of $U_1$.

We know from early experiments in manual control (McRuer and Jex, 1967) that the low–level brain and neuromuscular system (from $U_1$ through $U_0$ and back to $X_0$ and then to $X_1$ has a round–trip time delay of at least 0.2 seconds. So what is heard from one's own instrument is delayed 0.2 second or more from the time the action to produce a given note is initiated in the brain. But how can that be, for surely there is no instability of other irregularity in the controlled response. The fact is that $U_1$ anticipates the sound feedback because there is a succession of musical notes which the musician sees ($U_2$) on the score by "reading ahead." This has been called preview control.

## The 2nd level of supervisory control: composing and conducting the synchronization of musicians

The writing of music is essentially the programming of the instructions ($U_2$) to an intelligent musical production process. The lone musician then performs from reading those instructions (the score) or from memory (after practice). The writer gets feedback from performing the music himself or from listening to initial performances and revising, given some memory of how it sounded ($X_2$). The memory of musical patterns, especially among those gifted and experienced in music, is prodigious. It is common for writers and soloists to remember a whole musical piece.

With multiple musicians, of course, a conductor sets the pace and brings them into synchrony with his baton, a second meaning of $U_2$. Both the writer and the conductor adjust their renditions to the capabilities of the musicians and their instruments, much as the manual controller quite naturally adapts his control actions to the dynamics of the process being controlled. Conductors are also known for their incredible memories. This writer has had the pleasure of watching Seiji Ozawa conduct the Boston Symphony Orchestra on many occasions using no musical score whatsoever.

We are beginning to understand the neurobiology of how with practice the inter-neuronal connections are established so that hearing and playing one note or pattern of notes automatically triggers in the brain the playing of the ensuing pattern of notes. But full understanding of memory and performance of music or anything else at this level will take many more years.

## Music as virtual reality: the power of metaphor

The phenomenon of virtual reality has become relevant to the control community and it should become relevant for the music community.

### Telepresence and virtual reality

Those of us interested in human control, particularly remote control, know that these days it is becoming increasingly practical for a person to do a task anywhere without actually being there; this is called *teleoperation* (Sheridan, 1992). Further, by use of special new interface technology a person can see, hear, and possibly touch an environment that is arbitrarily remote in space — and actually feel present in the remote location; the latter is called *telepresence*.

With respect to vision, telepresence is accomplished by wearing a head-mounted video display which drives a video camera at the remote location, so that, whatever the position and orientation in the local space (where the observer is), the video camera assumes the same relative position in the remote space. Thus the observer sees what he or she would see as if present in the remote space. The sense of telepresence is dramatic.

With respect to hearing, telepresence is accomplished by means of two microphones at the remote site which are positioned in correspondence to the positions of the observer's two ears. These transmit sounds back to earphones on the observer's head. By further use of a *head-related transfer function* (which duplicates the front-back and up-down spectral filtering of the outer ear), one can locate sound sources with respect not only to left-right but also to front–back and up–down. This technology is well developed but is still a bit expensive for the commercial market.

With respect to touch, telepresence is accomplished by connecting the hand to a mechanical device that exerts differential force back on the skin duplicating the forces that are being transmitted and applied to objects in the remote environment. This technology began with force–reflecting master–slave manipulators and is now pushing in the direction of producing more subtle haptic feedback (e.g., data gloves) (Durlach and Held, 1995).

Now consider that instead of head, ear and hand position producing sight, sound and tactile images that are generated by events in an actual remote environment, the head, ear and hand positions cause the sight, sound and tactile images to be produced artificially, i.e., by computer. This, of course, is technology under active development. The experience of using such technology, and the field itself, are commonly referred to as *virtual reality* (though that being an oxymoron, *virtual environment* or *virtual presence* are probably more appropriate terms).

## Suppression of disbelief; music as metaphoric existence

The MIT Press journal *Presence: Teleoperators and Virtual Environments* has seen an active discussion in recent issues on the nature of "presence," virtual and otherwise (one is reminded of the various other uses of that term, e.g. ontological physical presence, divine presence, stage presence).

Psychophysical measures have been proposed, ranging from simple subjective rating scales, to measures based on the tendency to make natural bodily responses to virtual events (e.g., closing one's eyes or "ducking' one's head if a virtual object is seen to be on a collision course), to the use of visual or auditory masking noise to determine how little noise is required before one can no longer discriminate virtual from real (Sheridan, 1996).

The "presence" research community agrees on this empirical fact: the sense of "presence" in the virtual environment is enhanced by voluntary suppression of disbelief (that a virtual environment is not a real one). This is probably the same phenomenon that allows a person to be hypnotized, or to have a religious experience (Sheridan, 1998). Actually there are many forms of virtual reality in which people participate and can let themselves be "carried away," and most have been around for centuries: story–telling, theater, photography, television, etc.

And here is where music comes in. I would argue that music (which physically is just patterned sound), whether live or recorded, engenders an auditory virtual reality. (I am not referring here to the virtual reality of stereo or surround sound recording, though that helps create the virtual presence). Music is music because it stimulates imagination, provokes moods, and puts the listener "in another world." Of course that is nothing new for musicians, since they intentionally try to capture the sound patterns of running brooks, fluttering birds, or thunder claps, as well as the much harder-to-describe gamut of human emotions (from Pathetique and Blues to Ode to Joy and the 1812 Overture).

The sound patterns, in other words, strike not only a mechanical resonance with the natural frequencies of the human body, making us want to dance, but also strike an emotional, even spiritual, resonance through use of musical metaphor.

The technology of virtual reality, now much influenced by control engineering, has truly triggered a new interest in the very old ontological problems: What is real? What does it mean to exist? What is music? Where does it take the listener?

## References


Durlach, N. I. and Mavor, A. S. (Eds) (1995). Virtual Reality. Washington, DC: National Academy Press

McRuer, D. T. and Jex, H. R. (1967). A review of quasi-linear pilot models. IEEE Trans. Human Factors in Electronics HFE-4, no. 3, pp. 231-249

Sheridan, T. B. (1992). Telerobotics, Automation, and Human Supervisory Control, Cambridge, MA: MIT Press

Sheridan, T. B. (1999). Descartes, Heidegger, Gibson and God: toward and eclectic ontology of presence. Presence, 8 (5), pp. 549-557

Sheridan, T. B.(1996). Further Musings on the Psychophysics of Presence, Presence: Teleoperators and Virtual Environments, Vol. 5, No. 2, Spring

# Shaping Time in Music

*Horst–Peter Hesse*

Horst–Peter Hesse was born in Hamburg, Germany, in 1935. He studied, among other instruments, piano and organ as well as conducting at the Konservatorium Hamburg, directed a choir and led a private school of music in Hamburg. At the University of Hamburg, he studied music science, psychology, philosophy and phonetics and received his PhD with the thesis Die Wahrnehmung von Tonhöhe und Klangfarbe als Problem der Hörtheorie <The perception of pitch and tone quality as problem of the hearing theory, in German>. He was sound engineer at the Hamburg State Opera and scientist at the University of Göttingen. After his habilitation in the area of systematic music science, he taught at the universities of Hamburg, Hildesheim, and Salzburg. Since 1988 he is Professor for Theory of Music at the University Mozarteum Salzburg and leads the department for basic musical research.

## Introduction

The shaping of time in music highly determines its character of movement and expression. This topic is an extensive field, which has been treated in musicological studies from different points of view, for instance Kurth (1931), Behne (1972), and Epstein (1995). I would like to focus upon some special aspects, in particular new methods of measurement and graphical representation.

Composers from the baroque era to the present have emphasized in particular the importance of determining the »right« tempo in the performance of any composition. Richard Wagner, for instance, wrote in *Über das Dirigieren* (1869): *"From the choice of tempo you'll immediately see whether the conductor did realize the music or not."*

From that statement it seems that there is only one adequate tempo for every piece. But in practice conductors and players choose very different tempos, and these are correlated to different character of expression. From this discrepancy arises questions about the liberty and the limits of tempo option in musical performance.

In any case the choice of tempo must not be guided by arbitrariness but should be accurately controlled by intention. We at the *Mozarteum* in Salzburg have therefore developed a special training program for musicians studying conducting.

## Theoretical background

First, let us have a look at some theoretical implications: A crucial point for the solution of tempo problems is the distinction between the composed work of music, the *opus*, and the performance of music, the *execution*. The execution is unfolding in absolute time, it is part of the physical world, while the opus is a spiritual creation, which is existing – even if not being performed – outside the physical world. The opus indeed comprises time – shaped time – but this time structure exists outside the absolute time space. The Polish philosopher Roman Ingarden (1962) called the opus an *intentional object*.

The opus is a structure defined by pitch and time relations, and these are transposable *gestalt qualities*. Elements of the *relational pitch space* are intervals rather than absolute frequencies. If you put intervals in sequential order, you'll get melodies; if you put them in simultaneous order, you'll get chords. In melodies or chords every frequency can be changed, but the melody or the chord are kept unchanged, if the relational order in pitch space – the intervals – is preserved. If you go to perform an opus, you have to transform the pitch relations into absolute frequencies, you have to choose a tuning standard, for instance a = 442 Hz.

The same facts are essential in the time domain, which we call *relational time space*. The conductor is free in choosing that absolute tempo, that – from his point of view – will make the best representation of the music. But – just as the pitch relations – he has to preserve the time relations, which represent the opus. The opus comprises different kinds of time relations. These relations are subdivided in micro-order, the metric / rhythmic system, and macro-order, the field of proportional tempo. Let us have a look at the latter.

Take, for example, a change of tempo whithin a piece of music. In tempo "one" the beat duration may be 1.0 second, in tempo "two" 0.75 seconds. That means an acceleration. The proportion of the beat durations reads as follows: beat duration in the second part to beat duration in the preceding part of the piece is 3 : 4. If you express the tempo by the metronome markings, the marking of tempo II is 80, and of tempo I is 60. Now it is the inverse relation: The proportion is 4 : 3. The difference between the perceived tempos correspond to the proportion of the metronome markings.

The difference between both metronome values is 20. If you take the same difference downward from 60, the result is 40. That means a slowing down in proportion to tempo I of 2 : 3. The same differences do not mean the same facts. The steps whithin the metronome scale are not equal. Therefore you cannot use the metronome markings in statistical calculations. But some people did.

## Method

For reasons mentioned we use a logarithmic scale for tempo measurement:

T(x) time distance to the preceding pulse in milliseconds

p(x) number of pulses per second

$$p(x) = \frac{1000}{T(x)}$$

ld(p) tempo measure (dyadic logarithm)

$$ld(p) = \frac{\log p(x)}{\log 2} + 1$$

M ld(p) mean tempo

$$M\ ld(p) = \frac{\Sigma\ [ld(p) \cdot T(x)]}{\Sigma\ T(x)}$$

If x is a point of time and T(x) is the beat period, that is the time distance from one beat to the preceding beat, p(x) is the number of pulses per second. Differences in perceived tempo correspond to the proportion of pulses per second. We do express this proportion by the dyadic logarithm. – We add 1 to this logarithm to shift the zero point of the scale to the beat period of 2 seconds. That is equivalent to the metronome marking 30. The result is our *tempo measure* ld(p).

This tempo measure is representing the perceived tempo and tempo differences in *interval scale quality*, that is: the same differences in tempo are represented by the same difference of ld(p). Every doubling of tempo results in an increase of the tempo measure by one. That means: the metronome marking 60 is equivalent to the tempo measure 1, metronome marking 120 is equivalent to tempo measure 2 and so on.

With the aid of this tempo measure it is possible to represent tempo and changes of tempo graphically. In Figure 1 you see the original tempo instructions of Beethoven for his symphony no. 8, transformed from metronome markings to the logarithmic tempo measure.

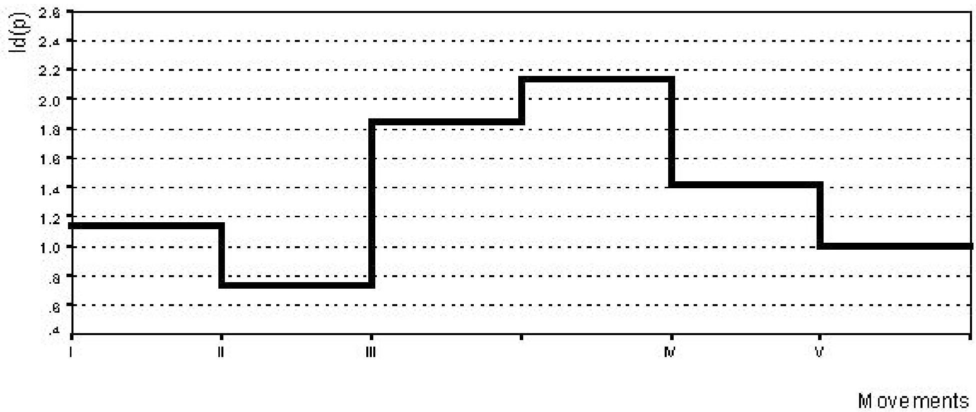



*Figure 1:*
*Beethoven: Symphony No. 6. F major, op. 68*
*Beethoven's Metronome markings*

**First**: In the diagram you can see the course of absolute tempo within the symphony – the change of tempo from movement to movement – as it was intended by Beethoven.

**Secondly**: You can easily identify tempo relationships. For instance: From first movement to the second movement and from fourth to fifth movement you see tempo reductions. In both cases the differences of the tempo measure ld(p) are equal. This means the same tempo proportion. The absolute tempos are different, but the proportion is equal. In this case the difference of ld(p) means a reduction to 75 percent of the preceding tempo. The *tempo factor* (TF) is 0.75. This is equivalent to the proportion 3:4.

$$TF = \frac{p(x_2)}{p(x_1)}$$

**Thirdly**: It is easy to compare different interpretations. For instance Michael Gielen (Figure 2): The first movement in his interpretation agrees with the tempo determined by Beethoven. The tempo changes are in the same direction, but the proportions are enlarged. The tempo factor second to first and fifth to fourth movement is nearly 0.66, that means the proportion is 2:3 instead of 3:4.

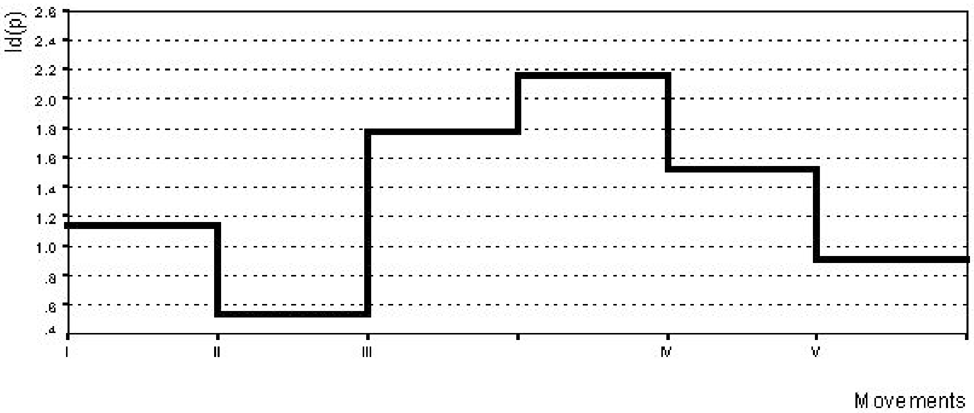



*Figure 2:*

*Beethoven: Symphony No. 6. F major, op. 68*

*Michael Gielen, Sinfonieorchester des SWF (1989)*

Claudio Abbado's interpretation (Figure 3) does show the same tempo profile in general, but you see a shift of the absolute values and different proportions, especially in the first and second movements.

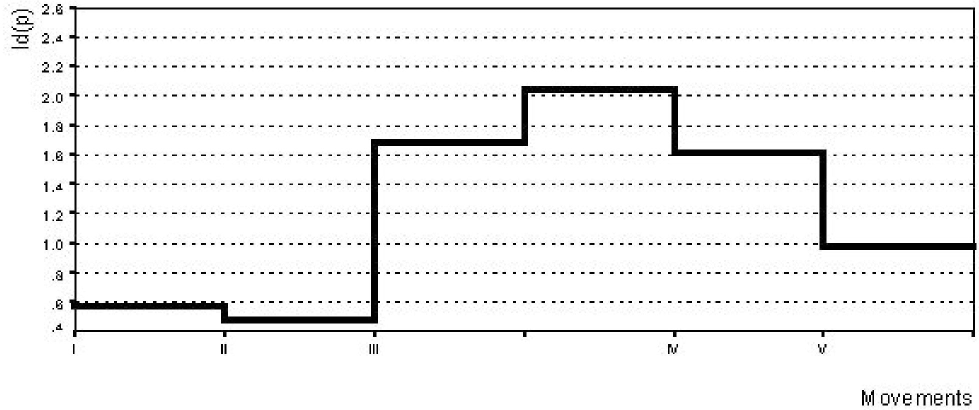



*Figure 3:*

*Beethoven: Symphony No. 6. F major, op. 68*

*Claudio Abbado, Berliner Philharmoniker (1989)*

Wilhelm Furtwängler's interpretation (Figure 4) in contrast to Gielen's and Abbado's is very different, the tempo profile of the whole symphony as well as the absolute values and the proportions. In the first movement he has chosen nearly the same tempo as Abbado, but this tempo is only 2/3 of Beethoven's tempo. Beethoven indicates slowing down in the second set, Furtwängler accelerates in the same amount. The first part of the third movement is slower, the second part faster than Beethoven's markings. Last movement is running exactly in Beethoven's tempo.

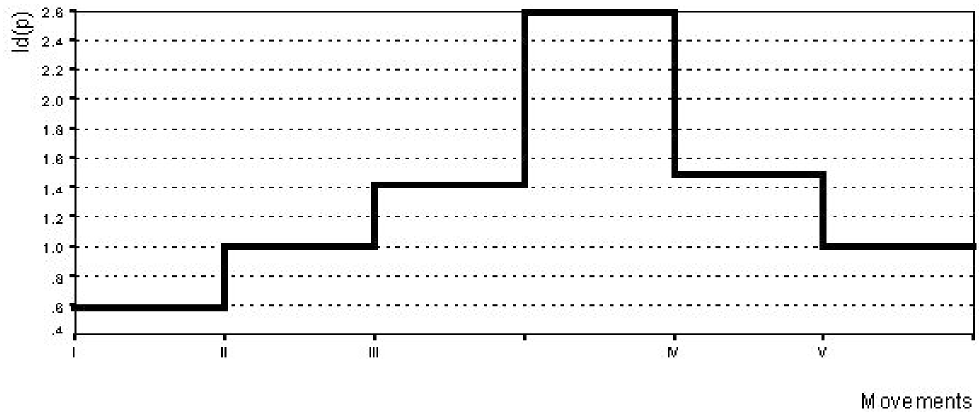



*Figure 4:*

*Beethoven: Symphony No. 6. F major, op. 68*

*Wilhelm Furtwängler, Wiener Philharmoniker*

Arturo Toscanini's interpretation (Figure 5) does show some similarities to Furtwängler's at the beginning. But his absolute tempos are more similar to Beethoven's with the exception of the last movement, which accelerates. The observations outlined could be the basis for a detailed comparison of interpretations.

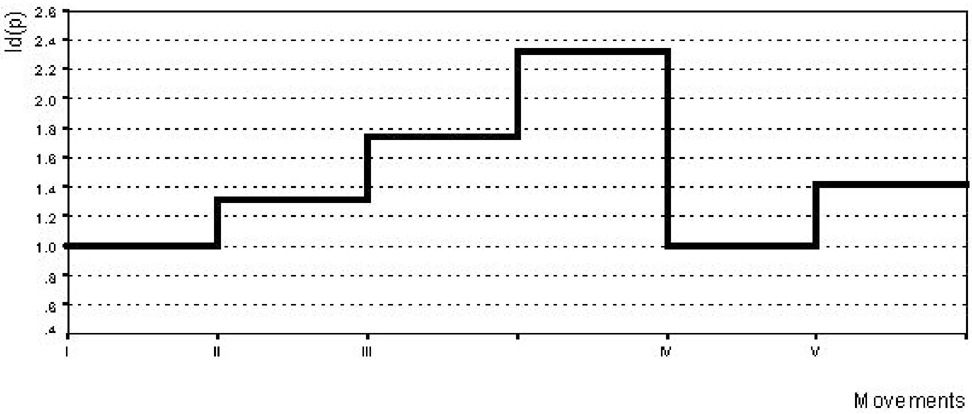



*Figure 5:*
*Beethoven: Symphony No. 6. F major, op. 68*
*Arturo Toscanini, NBC Symphony Orchestra*

## Application in music education

At the *Mozarteum* we use these kinds of diagrams for the training of students, who study conducting. For example we play music comprising different tempos and challenge the students to reproduce the piece and keeping the same tempos. Or the task is to produce a verbally given tempo profile including accelerando and rallentando. Another task is to change the absolute tempo but keep the proportions constant and so on.

We do record the musical tempo a person produces by using the *tapping method*. The tested person himself or another person listening to the performance of the person being tested taps the beats of the music on a MIDI-keyboard. The MIDI-files recorded by a sequencer get transformed to calculatable ASCII-dates by an auxiliary program and are subsequently evaluated.

It is obvious that the person, who is tapping the beats on the keyboard, should be a well-trained musician. But for musicians there are no considerable difficulties, because the ability to play synchronously with a given music is a basic achievement. But the capability of producing even or equally spaced movements of the hand is of course limited. See for instance this record:

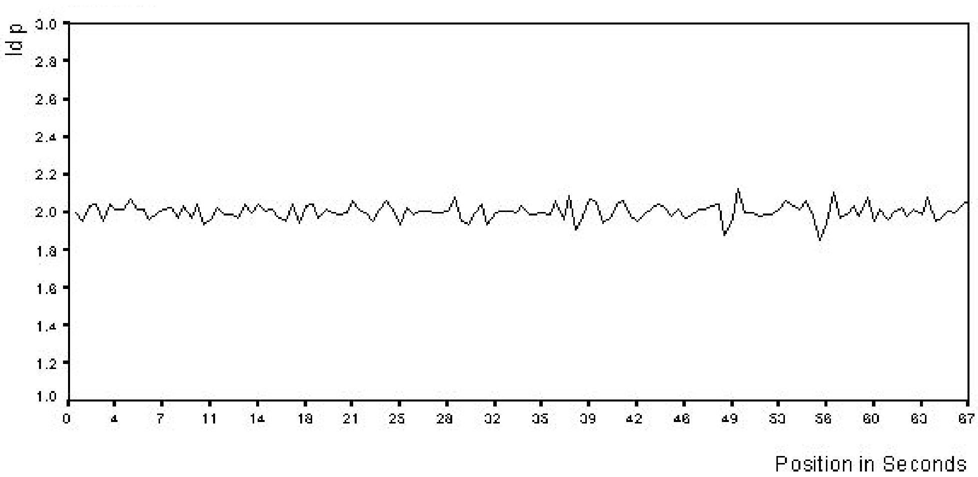



*Figure 6: Tapping, keeping equally spaced beats, ld(p)=2*

The task was to tap on a keyboard synchronously with a Metronome giving equally spaced beats. In this case the Metronome mark was 120, that means the beat period is 500 milliseconds. It can be seen that the time structure of the tapped series is not perfect. The slight inaccuracy of the tapping resulted in fluctuations of the tempo measure. But most deviations of the tapped periods compared with the desired values were below 30 ms, that is below 6 %. These deviations are not consciously recognizable in practice.

Another task is to continue the beat series of a Metronome after the Metronome stops. In this case the deviations are more marked, and you sometimes find a slowing down or acceleration in the course of time dependent on the given tempo.

Naturally there are large differences between the abilities of individual people. In the first task one can use the standard deviation of the tempo measure to compare their abilities. If one set other tasks perhaps other evaluations are efficient.

## Summary

Despite the crucial importance of shaping time in music there are relatively few results of experimental research investigating this phenomenon quantitatively and interpretating it in a rational way. This paper discusses a new technique allowing registration of musical tempo and its variations in time. The method has been developed to help conductors or soloists evaluate their ability to keep accurate time, but it could be transferred to other fields Being very effective, this technique facilitates detailed investigation of time perception up to the limits of human differentiational ability.

## References

Behne, K.–E. (1972). Der Einfluß des Tempos auf die Beurteilung von Musik. Köln: Arno Volk

Epstein, D. (1995). Shaping Time: Music, the Brain, and Performance. New York: Schirmer

Ingarden, R. (1962). Untersuchungen zur Ontologie der Kunst. Tübingen: Max Niemeyer.

Kurth, E. (1931). Musikpsychologie. Berlin: Max Hesse

Wagner, R. (1869). Über das Dirigieren. In Sämtliche Schriften und Dichtungen, Vol. 8, Leipzig

# Automation and the Making of the Violin: Some Thoughts on Systems Design Methodology

*Kensuke Kawai*

Kensuke Kawai is now TC chairperson of IFAC Human–Machine Systems, and an editor of IFAC Control Engineering Practice. Mr. Kawai met first Prof. G.Johannsen at Baden–Baden of the Man–Machine Systems (now it is called Human–Machine Systems) Symposium in early 1980s. Since then, Mr. Kawai visited Kassel University for IPC meetings of this symposium, while Prof. Johannsen visited Fuchu works of Toshiba located outskirts of Tokyo. In addition to the IFAC related meetings, Prof. Johannsen and Mr. Kawai met several times or more personally in Japan as well as in Germany. Mr. Kawai has been working in the design and development of control and computer systems used in the power generating plants, both nuclear and thermal power. Mr. Kawai was involved in the development projects such as "optimum steam temperature control of boiler (AR Model Method)", "turbine vibration monitoring and diagnostic Expert System", "advanced automation systems for start–up, shutdown, and normal operation" and "operator training simulator systems for thermal and nuclear power plants". Those results were discussed with him on several occasions to exchange the latest developments of theory and practice. Mr. Kawai has developed systems design methodology for the last three years, which is utilized throughout Toshiba Corporation, while he is now responsible for the strategic planning of Thermal Power Systems & Services Division.

## Abstract

The purpose of this paper is to describe the design process of continuous improvements both for automation and violin–making. Although these design problems seem to be quite different in nature, there are many common factors pertaining to the design methodology. The Voice of Customer (VOC), in particular, plays a very basic role for successful creation of a new systems and / or new products, since it is always so difficult to identify all the functional / structural details well in the upper front of the design phase. The evolutionary design approach based on the sound initial concept will leads to a remarkable result in automation design as well as in the making of the violin.

Keywords: Automation, Design, VOC, Composer, Performer, Violin, Violin–Making

## Introduction

In the field of HCI (Human Computer Interaction) studies in music, there are many approaches going on such as creation of new generation of musical instruments and new session systems.

Automatic accompanying systems, in particular, are also studied in order to realize new level of interaction between human performer and computer "accompanist". Although there are some successful experimental systems reported, there still needs a breakthrough in autonomous feature of playing on the part of computer accompanist (Katayose, 2001).

A few years ago, some Japanese newspaper said that automatic violin–playing apparatus was reconstructed by a German technician and installed as well as made open to the public at Hall of Halls in Kiyosato village located at a central part (Yamanashi Pref.) of Japan. This apparatus is called "Phonoliszt Violin", which consists of three violins and a piano as an accompanying instrument. This phonoliszt violin is invented originally in the late eighteenth century, all the mechanisms adopted here are basically ones of mechanical nature. As a hardware system, as shown in Figure 1, the level of completion is very high, but the author could not enjoy the performance and interaction between violins and a piano. Lots of works are still left to complete this apparatus as an excellent messenger of a composer to the classical music fans.

*Figure 1: Phonoliszt Violin at Kiyosato*

There is an interesting book available titled, "Aria–Eighty Years Old: A Story of Violin–Making over Forty Five Years" (in Japanese) by H. Itokawa (Itokawa, 1992). The writer of the book was a famous professor of Tokyo University specializing in Aeronautical Engineering and Systems Engineering. During the days of World War Two, he designed the fighter airplane named Hayabusa, which was realized according to the Voice of the Pilots. Since the end of the war he started the study on violin–making with his colleagues for some years. He retired from Tokyo University in 1967, establishing the institute of his own to continue his study or to write some popular books for the public. The book of Aria is written about the life cycle of his peculiar violin–making from its birth to its completion in 1992.

The author of this paper is a system engineer / designer in the field of instrumentation and control including automation system for power generating plants for more than twenty five years (Kawai, 1999), although he used to play a violin very enthusiastically for four years in the student orchestra. During the days of university orchestra, he enjoyed the violin concerts performed by *Ruggiero Ricci*, *David Oistrakh*, and *Yehudi Menuhin*, for example, while he also enjoyed playing the violin himself such pieces as violin concerto composed by *Mozart*, *Bruch*, and *Mendelssohn* and so on. Although he has some knowledge on the music and the violin, he is only an amateur player of this instrument, so the expertise knowledge related to music and the violin will be utilized mainly for the analysis and evaluation of the contents described in the book by Dr. Itokawa.

After graduation, the author had an intention to bridge the gap between theory and practice in the field of modern control theory. In addition to the long–lasting automation systems, he was involved in the systems development such as optimum steam temperature control of boiler process, turbine vibration–monitoring and diagnostic expert system, and operator training simulators for power generating plants. His automation system was developed within the social and technical conditions of the past power generating plants in Japan, and proved to be indispensable system for modern power plants there. He also expanded this advanced automation systems to those utilized in Australia, Canada, China, India, and the Middle East. In a different cultural / social conditions, the role of the operating staffs needs to be re–designed and re–evaluated in order to be economically feasible, technically viable and socially acceptable.

In a sense, the author had made every efforts to design an automation system to be welcomed and accepted as much as possible by the human operators throughout the world. Autonomous use of automation functions was the design goal of the automation system, which begins with identifying and listening to the Voice of Human Operators. In this paper, the author would like to review the vision of the next–generation automation system through the evolutionary design approach, comparing the design process of violin–making and automation based on the Voice of Composers and the Voice of Human Operators, respectively.

According to Prof. Itokawa's comments in his book, his violin was designed through such steps as follows:

- Step 1: Investigation of the intentions of the composers
- Step 2: Analysis of the frequency of sound patterns
- Step 3: Measurement of the sound-performance of the violin (a famous Stradivarius)
- Step 4: Analysis of the inner structure of the violin by wave mechanics
- Step 5: Reduction of the weight of the violin for the performer
- Step 6: Improvement of maintainability of the violin adjustment
- Step 7: Trial performance and evaluation by a world-class violinist (Yehudi Menuhin)

There was a criticism, during the course of the development, on his violin-making on the part of a traditional violin-maker (Murata, 1975), and it was difficult to find out the latest evaluation on his violin by other parties. The systematic design process, which created the unique violin, will be utilized here in order to validate the systems design methodology starting from the VOC –Voice of Customers (Ishii, 2001).

## Who is the Customer?

### Variation A: Violin-making based on the Voice of Composers

Dr. Itokawa developed a fighter airplane called Hayabusa, whose performance of a circular-flight was extremely high those days, based on the Voice of Fighter-Pilots. In order to collect the voice of the pilots, he lived with them to learn the true meaning of what they expressed using a metaphor. When he wanted to take a similar approach for violin-making, he and his staffs started to soliciting and analyzing the classical music for the violin of radio-broadcasting of *NHK (Japan Boadcasting Corporation)* and *FEN (Far East Network)* of the U.S. Armed Forces.

They analyzed all the pieces they had listened to and collected all the related scores in order to take data-driven approach. According to the frequency of the sound-appearance, they came to the conclusion that some sounds were more important than others from the composers point of view. It is quite unique that they analyzed those pieces from the Human-Machine Interaction viewpoint between the Composer and the Instrument. Later he realized the importance of the Voice of Violin-Performers and maintenance-technicians as well.

According to the opinion of the author of this paper, his approach might have been much more complete, if he adopted the composer-performer-instrument framework, in stead of a simple composer-instrument relationship. Even a world-class performer can be classified either as a good Strad player or a good player of Guarnerius. Just to indicate an example of the necessity to introduce the Voice of Violin–Performer, Y. Menuhin, a famous violinist, wrote the process towards the completion of a new unaccompanied violin sonata by B. Bartok in his book (Menuhin, 1977);

*"Bartok mailed me the score from Asheville, North Carolina, where he had been sent by his physicians, under sentence of death from leukemia. He had accepted an invitation to spend the summer of 1944 at my home, and was also interested in a proposal from the University of Washington at Seattle to continue his study of fork music with the Indians of the Northwest. Alas, both musicology and myself were robbed of the experience by his wasting disease. He could not travel so far. Instead he wrote to me:*
*I am rather worried about the "playability" of some of the double–stops, etc. On the last page I give you some of the alternatives. In any case, I should like to have your advice. I sent you two copies. Would you be so kind as to introduce in one of them the necessary changes in bowing, and perhaps the absolutely necessary fingering and other suggestions, and return it to me? And also indicate the impracticable difficulties? I would try to change them." (P. 223)*

Akiko Suwanai, a young Japanese violinist, who won the Tchaikovsky's musical contest in 1990 at the age of 18, wrote in her book (Suwanai, 1995), that she was advised by Isaac Stern the necessity to study the original score written by the composer to find why the "trill" should be played like that, and why the "bowing" should be like that. According to Stern, it is also important for the performers to be able to express the results of this why–why approach in words. This story is very interesting and stimulating from the systems–design–methodology view point, since the methodology of externalizing in words is advocated and utilized in the field of collective creation (Nakakoji, 2001).

One of the most difficult tasks or the most difficult question in his approach is how to identify the Voice of Composers in the future. Even today, it is usually said that the best–in–class violins are mainly those from Italian violin–makers such as *the Amati*, *the Guarnerius*, and *the Stradivarius* in the late 17$^{th}$ century. Did all these gifted violin–makers listen to the future voice of composers? Or their violins improved much higher than the level intended by the makers as a result of maturity improvement in time?

### Variation B: Automation design based on the Voice of Human Operators

In addition to the comprehensive automation system, which covers all the major operations during start–up to shutdown including normal and emergency operations, there was a project to apply and develop the new control algorithm of optimum steam temperature control using auto regressive model and dynamic programming in a boiler process. The development project itself proved to be successful to bridge the gap between theory and practice in control and operation of fossil fueled power generating plant. During the commissioning of this project, however, there was an incident and its quick recover was needed in plant major equipment, which led to the formation of "Automation review committee" (Uchida, 1981) by the engineers both from the power company and plant / automation suppliers.

During discussions after the plant disturbance,

- the final goal and objectives of the automation system,
- requirement definitions of human-machine interface,
- functions of the automation system, and
- the role of operators

were reviewed again to re-establish the real Voice of Human Operators.

Especially, how to give the necessary information at an appropriate time to the human operator was one of the major design-review items of automation system. The messages given by the automation system shall be output serially, considering the human operators single-channel structure of information processing capability.

The clear distinction between automatic and demand message output during start-up and shutdown, were reviewed just from the beginning again. The result of the analysis and its revised automation design were applied to this project, which improved the usability by the human operator and the safety and reliability of the power generating plant. Those aspects for engineering and maintenance, other than those of plant control and operation, were also analyzed to identify the management aspects of power generating plants, reviewing the voices of commissioning engineers, maintenance engineers and those of managers of the power company.

Although the voice of human operators in the past might be analyzed from historical perspectives, it is quite interesting to note that the voice of future customers in control and instrumentation shall be fully understood, since the similar phenomena named Innovator's Dilemma (Christensen, 1997) had happened in this fields such architectural transfers as:

- from process computers to engineering workstations,
- from engineering workstations to personal computers,
- from real-time operating systems to UNIX operating systems, and
- from UNIX operating systems to Windows operating systems.

What's coming next is still an open-ended question, although Norman advocated the concept of the information appliances in his book titled "The Invisible Computer" (Norman, 1999).

## Definition & Focus

### Variation A:
### Definition of a good violin and its focal points

The first three steps of violin-making by Itokawa corresponds to these steps.

- Step 1: Investigation of the intentions of the composers
- Step 2: Analysis of the frequency of sound patterns
- Step 3: Measurement of the sound-performance of the violin (a famous *Stradivarius*)

Even if his approach to investigate the intentions of the composers might be very good in principle, but was it really appropriate that the population of their music selection represented the optimum sources of voices of composers for violin-making? In the next step, the frequency of sound patterns could be analyzed by the proposed method, it is still an open question that the frequency of sound patterns could be utilized as an effective measure of composer's intention on which sounds he might have put a vital importance.

In the third step, how to measure a small displacement indirectly was a main theme without affecting the sound-performance of the violin. The theme of his doctoral thesis was actually on this measuring methodology. He identifies two important conditions for a famous violin, i.e.

- the tone sounds beautifully,
- the sound can be transparent and heard even in a distant location in a hall.

He used, for his analysis, violins of both ordinary-class and world-class, which was a Strad borrowed from a female violinist in Tokyo.

In order to strengthen the violin-making approach, the voice of performers is introduced as in the previous section. Just as an example by the comments of performers, Menuhin wrote as follows in "Unfinished Journey" (Menuhin, 1977):

> *"What is the interpreter's role? Certainly he is more than a simple transmitter. Between composer and audience he brings the living element and restores the pulse of life to the dry notes on the stave. What creates an interpretation is a very slight unevenness, originating in personal feeling, which recognizes that life does not proceed at an unchanging pace, but that blood and breath must quicken or slacken according to circumstance."*
> *(P. 428)*

### Variation B:
### Definition of a good automation system and its current practice

The first steps to reach to the successful automation are

- to define the objectives of automation system,
- to determine the scope and depth of automation including automation modes available, and
- to introduce the patterns of regulating methods such as direct digital control, supervisory set point control and the like.

The goal of automation should never eliminate the human operator, but rather it shall establish the automation with autonomous nature, which means that the human operator welcome the automation, or he or she has a positive attitude to use the automation interactively.

The objectives of automation system in Japan, were decided based on the social conditions of 1970s and 1980s and the scope and depth of automation were also subject to the technology level available, then. Starting from just a turbine run–up system, the automation system focused on the automatic operations during both start–up and shutdown of turbine and boiler, and it also focused on reduction of labor during normal operation, and restorative operations after plant emergencies such as FCB (Fast Cut Back) operation.

Although some important concepts were introduced such as changeover between control mode / sequence–monitor mode, the matching of plant operational mode with schedule calculation parameters, and advanced features of improved human machine interfaces, no overall measure was defined as a means of judging the appropriateness of the automation design, which corresponds to the objectives of automation. Very limited subjective evaluation was conducted as a usual practice, although there were few exceptions.

## Design Target & Analysis

### Variation A:
### Analyzing the Approaches of Violin–Making

In the step 4, analysis of the inner structure of the violin by wave mechanics was conducted.

As a result of this analysis, he came to the conclusion that important sounds for violin–making were found as A4, E4, D4 and A3. Out of these four kinds of sounds, both E4 and A4 are the sounds at high positions on E string, which must be played more conspicuously with ease. It is generally said that when playing the violin in its high positions, it is necessary to play the violin a little bit stronger with the bow coming closer to the bridge.

As a result of his analysis he made the belly of his violin much thinner to strengthen the sound of high positions with ease, and introduced the second bass–bar for E string in addition to the conventional bass–bar as a support of his unique violin. He also described his way of selection of wood and aging method to accelerate the age or maturity of his violin much faster, while he disregarded the characteristics of varnish relying upon the analysis by wave mechanics.

Now, coming back to the voice of performers Menuhin wrote, as an example, (Menuhin, 1977):

> *"The interpreter must of course create, but there are degrees of creation and no doubt composition is the highest. My compensation is to commission music, an activity which offers many pleasures. For the composer there is the satisfaction of working for someone willing to risk the results; for the interpreter, to be associated with the act of creation fulfill a part of his nature which may otherwise be frustrated. The creative, I firmly hold, is the normal human condition, whether displayed in the kitchen, in house–keeping, in violin–playing or in any of a hundred ways." (P. 430)*

## Variation B:
## Analyzing the Approaches of Automation Design

In our approaches to a successful automation design, the author and his colleagues needed in–depth analysis of a new concept of "chain of triggers upon plant events". In this concept automation knowledge can be described by state space expression of N–inputs and 1–output combination, All the analog–type input could be treated as digital–type status by introducing the appropriate limit values to them. This means that we can treat in a consolidated way both the analog value with its limits and digital value now.

The next basic framework depends on the logical expressions by PANS (Pre–conditions) / CANS (Complete–conditions) / TANS (Timing conditions) as explained elsewhere (Kawai, 1999). This is a sort of production system, which specifies the knowledge of automation efficiently and effectively. In order to make this knowledge more understandable, packages of expressions were introduced, which defines plant master status (PMS), macro status determiner (MSD) of pre–conditions / complete–conditions, and the like.

Separation between the production rules and the procedural expression of feedback control was another consideration to accelerate the re–use of the automation knowledge from one project to the next. Visualization of automation logic and on–line real–time accessibility to automation logic were also important features for the human operator, which intensifies the situation awareness of the status of the plants.

## Detail Design & Implementation

### Variation A:
### Detail design and evolution of violin–making

- Step 5: Reduction of the weight of the violin for the performer
- Step 6: Improvement of maintainability of the violin adjustment

Step 5 and Step 6 of his approach correspond to the detail design and refinement of the violin–making. He was so confident of his violin, and he went to show it to the performers several times, but most of them did not even try to play his violin. One day he realized that his violin was 50 grams or so heavier than that of typical violins, whose weight is usually from 370 to 380 grams. Due to his extra bass–bar for E string his violin had more weight than the other one.

For several years he was involved in the solution of this problem with the help of a traditional violin–maker. They made every effort to reduce the weight of the violin without affecting the sound–performance of the instrument. Further reduction in the violin weight was needed. During the joint efforts he realized the importance of listening to the voice of technicians, who will conduct adjustments of the violin regularly. His violin has extra bass–bar, which made the maintenance work rather difficult.

Time has already passed by forty five years since he started the violin–making as a study of his research. One day the traditional violin–maker proposed to Dr. Itokawa that he would like to move sound–post from the original position to under the extra bass–bar directly in order to improve the maintainability of his violin. Although he was astonished at the idea, but he ran the risk of this approach and let his technician to do the task of this modification.

Let's listen to, now, the voice of the performer, i.e. interpreter again (Menuhin, 1977):

> *" The interpreter's duty is threefold. First he must master the numberless muscular pressures which in every position on every string will produce every quality of sound. Then, having learned the phonetics of his language, he must put them together to convey a message, and to do this must have a fullness in himself to express before the composer's fullness finds a response. Lastly, he needs an understanding of the composer's style, a corrective to the urge to express himself rather than the music. Thus, he puts all his equipment, his skill, the raw material of his whole life at the service of another man's vision – a vision which has become his own without, at the moment of performance, the need for thinking about it." (P. 429)*

## Variation B:
## Detail design and evolution of automation design

As the journey of violin-making of 45 years is drawing near the end of its time period, so the automation design of 25 years is also coming to its close. As a variety of available technologies for this automation increases, automation design evolved into a better one to solve those problems encountered during commissioning and after the taking over of the power generating plants. Especially, human-machine functions were reviewed again and again to achieve the evolutionary improvement over the long period of design improvement. Although the very basic design concept were unchanged, this evolutionary approach enabled the introduction of advanced features of automation.

The followings are some typical improvements in automation design:

- higher reliability of automation by duplicated system configuration,
- realization of duplication of CPU, shared memory, and controller backup,
- introduction of network architecture for distributed system configuration,
- introduction of operator-station concept, enabling all alarming and operation functions on a single client (Workstation / PC), and
- improvements of schedule calculation method, covering wider scope and depth of unit start-up operation and unit shutdown operation as a cycle.

The maintainability consideration was one of the important aspects of successful automation. Not only the editor called Background processor used for the maintenance of production rules of automation logic, but also the following maintenance functions were made available during the last 25 years of continuous improvement:

- maintenance function for data base and calculations,
- maintenance function for graphics and tables,
- maintenance functions for performance calculations,
- maintenance function for control procedures and operations, and
- maintenance function for commissioning.

## System Evaluation

### Variation A:
### Overall evalution by a world-class violinist

- Step 7: Trial performance and evaluation by a world-class violinist (Yehudi Menuhin)

As a final evaluation Dr. Itokawa asked Mehuhin to play his violin of 45 years of evolution. After the trial performance Mehuhin commented that the sound of the E string of this violin was very good. Almost 45 years has passed since he and his staffs started the research of creating a new type of violin. Although the author could not find the latest information on this violin, it was reported in a newspaper that a manufacturer of music instruments succeeded in copying a Strad very economically using high-tech type of manufacturing technology.

Finally, Menuhin wrote in his book (Menuhin, 1977):

> *"Perfection cannot be achieved unless its pursuit becomes a way of life. My goal has been so to play the violin that whatever I play is an exercise for whatever I might play. Concentrated observation and practice minuteness are gradually absorbed; the conscious brain is short-circuited;" (P. 402)*

### Variation B:
### Overall evalutaion in different cultures and countries

As a part of final evaluation of the automation design, the basic design of this automation was applied to realize the plant automation in different cultures and countries, such as Australia, Canada, China, India, and Kuwait. Needs for flexibility of automation in these countries were not so strong compared with the case of Japanese utilities (where super-critical once-through boiler is used), since in these countries they introduced limited level of automation into the plant with sub-critical drum-type boiler.

In the next decade, gas-fired combined cycle plant will increase much more as a result of innovation in the field of power generation. Although the control of the gas turbine (GT) might be very complicated, they are carried out by a dedicated controller attached to GT. Other operations for HRSG (Heat Recovery Steam Generator) and BOP (Balance of Plant) as a part of comprehensive automatic operation are essentially simple, and the focus of the control and operation will be on the revolution in safety and security of human machine systems and the development in intelligent and critiquing systems for human operator assistance.

## Conclusion

Ms Suwanai released this year a new CD named Crystal (Suwanai, 2001), which covers best pieces of her performance including Bach's Partita No.3 in E, BWV1006: 1. Preludio. In this CD additional video is included, which shows the scenery during recording with her comments. She commented in this video that, to her surprise, the target level of her performance improved much more even while recording!

The author has an old French violin made by *Audinot*, who is the apprentice of *Vuillaume*, who is sometimes called "Stradivarius in France". The author does not know which methodology of variation, Variation A or Variation B, might be helpful for the improvements of his violin-playing, he might start his violin practice again, accompanied by his wife Yasuko based on the voice of human "accompanist".

## References


Christensen, C. M. (1997): The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail, Harper Business

Hall of Halls Museum (Moeginomura) (2001): Phonoliszt Violina – Mechanical Violin (Automatic musical instruments selection Vol. 8), CD (HD-1008)

Ishii, K. (2001): Director Mfg. Modeling Lab, Design Division, Dept. of Mechanical Engineering, Stanford University (http://me217.standord.edu)

Itokawa, H. (1992): Aria-Eighty Years Old: A Story of Violin-Making over Forty Five Years (in Japanese), Bungei-Shunju

Katayoshe, H. (2001): Man Machine Interaction in Music Application, J. of Systems, Control, and Information, 45-6, pp. 328-333

Kawai, K. et al. (1999): Advanced Automation for Power-Generation Plants-Past, Present and Future, Control Engineering Practice, Vol. 7, pp. 1405-1411

Menuhin, Y. (1977): Unfinished Journey, Futura Book

Murata, Z. (1975): Violin (in Japanese), Iwanami

Nakakoji, K., et. Al (2000): Computational Support for Collective Creativity; Knowledge Based Systems Journal, 13-7/8, pp. 451-458

Norman, D. A. (1999): The Invisible Computer: Why Good Products Can Fail, The Personal Computers Is So Complex, and Information Appliances are the Solution, The MIT Press

Suwanai, A. (1995): Violin to Kakeru (in Japanese) <Soaring High together with a Violin>, NHK

A. Suwanai, A. (2001): Crystal, CD: UCCP-3041, Philips

Uchida, M. (1981): Totally computer automated control system in a thermal power unit, Proc. $8^{th}$ IFAC Triennial World Congress, Vol. XX, pp. 135-141

# Invention and Innovation in Technology & Art

*William B. Rouse*


## Abstract

Technology and art are usually viewed as two very different domains of human endeavor. The latest leading–edge computer technology and the current cutting–edge jazz, for example, would seem to have little in common. In this essay, however, it is argued that invention and innovation in technology and art involve similar behavioral and social processes. This assertion is evaluated by contrasting innovations in transportation and computing with innovations in jazz and modern painting.


## Introduction

Technological innovation has received much attention in recent years as a central source of economic prosperity. This claim is far from a new insight and could easily have been made during most past eras. Technology has long been a "lever of riches" (Mokyr, 1990).

Innovation in a much broader sense is central to social and cultural prosperity. Innovation in art – music, theatre, painting, etc. – enables the intellectual and aesthetic growth that are central to a thriving society. Further, innovations in different domains of activity affect each other, in part lowering the barriers between C.P. Snow's two cultures (1965).

In this essay, I explore the nature of invention and innovation in technology and art. My thesis is that the behavioral and social nature of these phenomena is quite similar in these two domains of activity, both involving creative and motivated people who try to escape the constraints of the past. Further, art is every bit as inventive and innovative as technology, often in surprisingly similar ways.

This exploration first addresses the nature of innovation and differentiates the concepts of invention and innovation. I then consider how innovation can be viewed as a process of identifying new patterns which gain broad acceptance beyond their originators. These preliminaries provide the basis for exploring two streams of technological innovation – transportation and computing – as well as two streams of innovation in art – jazz and modern painting. Finally, I speculate on the implications of the parallels drawn.

## Invention & innovation

Innovation via technology has in recent years become an increasingly popular topic in the business literature, in part because of large enterprises' perceptions that it is quite difficult to do new things both quickly and well (Christensen, 1997; Rouse, 2001). As noted by *The Economist* (1999), *"Unlike cutting jobs or making an acquisition, innovation does not happen just because the chief executive wills it."*

Bill Rouse first met Gunnar Johannsen in 1971 at the Annual Conference on Manual Control in Los Angeles. Gunnar had just completed his Ph.D dissertation and Bill was in the middle of his. Their next encounter was in 1976 at the NATO Supervisory Control Workshop in Berchtesgaden, followed in 1977 at the NATO Mental Workload Workshop in Mati, Greece. In 1977–78, Gunnar spent a sabbatical at the University of Illinois working with Bill's research group. In 1979–80, while Bill spent a sabbatical at Technical University of Delft, he traveled frequently to FAT to continue his collaboration with Gunnar. Since then, Bill and Gunnar have continued their relationship via occasional meetings at various international conferences and workshops.

The many debates and discussions of this topic often stumble over definitions of innovation. The following alternatives capture how innovation is viewed in this essay:

- *"Innovation is the introduction of change via something new. Many innovations take advantage of one or more inventions, but these inventions are not the innovations. The vast majority of inventions and good ideas in general do not result in change. They do not become part of products or services in people's hands, being used to be productive, make life easier or safer, or bring enjoyment."* (Rouse, 1992).
- *"One must be careful to distinguish innovation from discovery. You can only manage discovery by setting direction and hiring people to work in that direction with the hope of great discoveries. Innovation, the process of taking a discovery or idea to the market, is something that must be managed carefully, and we work hard to do this."* (Brinkman, 2000).
- *"My definition of innovation is invention, or doing things differently, that leads to business success. By this definition, without a business success, there is no innovation."* (Heilmeier, 2000)
- *"Research is the transformation of money into knowledge; innovation is the transformation of knowledge into money."* (attributed to Bayer).

The distinction between innovation and invention or discovery is very important. Many enterprises consider themselves to be innovative, despite flat sales and sagging profits. In such situations, it is often the case that they are reasonably inventive, but not as innovative as they perceive themselves to be. Xerox's failure to translate it's personal computer inventions to market innovations – discussed later — provides a good example (Smith & Alexander, 1988).

Presented with this observation, people often say, "But, our employees are full of good ideas and have created lots of neat things." This assertion is almost always correct. Their perceptions that their employees are inventive is usually well founded. However, at the same time, this plethora of inventions has seldom resulted in change in these companies' markets or, in general, for these organizations' constituencies. Value provided to the marketplace or for constituencies has not increased. Their inventions did not result in innovations.

This distinction between invention and innovation directly translates from technology to art. Whether it be a jazz session or an art exhibition, you frequently encounter much invention. Certainly you also encounter much imitation. However, the same is true for technology where good ideas are used again and again.

Occasionally, inventions are adopted by others, replicated and improved, and become part of the mainstream within some genre. In the process, these inventions change the mainstream, usually displacing older inventions which now become curiosities for collectors of various types. In this way, the new inventions have succeeded in becoming innovations.

There is perhaps, at this point, an important distinction between technology and art that should be noted. Displaced technology usually no longer is employed to do the work for which it was originally intended. Artistic innovations, in contrast, can become more valuable despite their lack of currency with contemporary artists.

For example, the value of a van Gogh painting increases with age, while the value of a vacuum-tube radio does not. Classic paintings, symphonies, etc. remain popular to the public's eye and ear, but classic technologies remain interesting only in museums. In both cases, however, inventions that fail to become innovations disappear.

The distinction between technology being used and art being appreciated pertains to the evolution of an innovation subsequent to achieving this status. If we follow this evolution far enough, we find that technology innovations, while no longer used, become appreciated as art. One need only visit the technology collections of the Smithsonian in Washington or the Deutsches Museum in Munich to appreciate this conclusion.

## Patterns & innovation

Innovations in microelectronics and jazz, for instance, appear to have little, if anything, in common. However, if my thesis about the commonality of invention and innovation across domains is to be supported, they must have something in common. Building on the seminal work of Christopher Alexander (1964, 1977), numerous commentators have argued that patterns and pattern languages are the common threads across domains.

A pattern is a rule or guideline. The rules by which patterns connect are termed pattern languages. Such languages can be represented by a prose description or often by a directed graph depicting the relationships among patterns. Alexander originally developed pattern languages to communicate proven solutions to architectural problems.

Pattern languages have particular structural properties associated with directed graphs (Salingaros, 2000). Beyond architecture, they have been applied to a wide range of disciplines, e.g., computer software design, human–computer interaction, and musical composition (Borchers, 2001). For this reason, it appears that the notion of patterns is the key to crossing the apparent boundaries between technology and art.

Patterns are regularities that are discovered in nature or invented by humans. There can also be "natural" human–made patterns created, for instance, by mathematicians with fractals. Patterns can characterize relationships among forces, structures, time, etc. in technology or among form, color, texture, time, etc. in art.

New patterns are discovered or invented. Those patterns that "work" and hence create change beyond the originators become innovations. Most new patterns do not work and, consequently, are not broadly adopted to become innovations. Nevertheless, the invention process is essential to creating a "funnel" of ideas, the spout of which will yield occasional innovations.

New patterns involve new rules of the game, whether the game is technology or art. Patterns that involve no rules may seem attractive, but they inherently cannot work because the broader community will not know how to adopt them. Thus, as amply illustrated later in this essay, patterns that become innovations involve rules that work and can be broadly adopted.

Where does creativity fit into this process? Several years ago, I compiled all the studies I could find on creativity in engineering (Rouse, 1986). Looking for the characteristics of engineers judged to be creative in these many studies, two conclusions emerged:

- Creative people consume large amounts of wide varieties of information
- Creative people see connections and distinctions not seen by others

A behavioral explanation of these characteristics, especially the latter, can be drawn from the constructs of psychological integration and differentiation (Csikszentmihalyi, 1990).

People with the above characteristics tend to be very inventive – full of ideas that imply new rules or patterns. On rare occasions, their inventions will eventually become innovations, although history has shown that seldom will these originators be the agents of these innovations (Burke, 1996). Nevertheless, their inventions will have been key inputs to the wide end of the aforementioned funnel.

Inventing new patterns often involves breaking real or imagined constraints, for example, the notion that paintings should be limited to subjects in formal poses indoors. The Impressionist painters moved outdoors and captured subjects in natural settings behaving naturally. Modal jazz artists broke chordal constraints to focus on scales.

Of course, new patterns inevitably encounter new constraints. For example, Monet frequently complained about the weather not cooperating with his desires to paint outdoors. More seriously, new constraints often prompt discovery or invention of new patterns and, when these inventions work, eventual innovations.

Summarizing briefly, I am arguing that invention and innovation in both technology and art involve discovery of patterns that work and are eventually broadly adopted, if only for a period of time until new constraints are encountered. Further, the behavioral and social processes underlying this discovery and adoption are common to all people whether they are engineers or artists.

This assertion that the nature of invention and innovation is essentially similar for technology and art is best evaluated by considering several examples. The next section elaborates these examples, first for technology in the realms of transportation and computing, and then for art in the domains of jazz and modern painting.

## Examples of innovation

Innovations in transportation and computing have dominated economic development for the past 200 years. Innovations in music and painting have reflected the social and cultural changes that have accompanied this economic development. Jazz and modern painting, which are reviewed here, provide compelling examples of how society has broken with the well-structured, more formal past.

### Innovations in transportation

The examples from transportation and computing are drawn from my book *Start Where You Are* (Rouse, 1996), which provide extensive case studies of technological innovation. The references to many of the developments and events noted here can be found in this book.

Before the early 1800s, the dominant forms of transportation — horse, stagecoach, sailing ship, and so on — had not changed substantially in centuries. Then, within roughly 100 years, we had steamboats, railroads, automobiles, and aircraft. In the process of moving from stagecoaches and canal boats to jet planes, humankind changed the speed at which it traveled by a factor of 100. Trips that once took days, now take minutes.

Robert Fulton is traditionally credited with the invention of the steamboat. He was fortunate, however, to be able to build on a variety of earlier efforts. For example, several steamboats were demonstrated following James Watt's improvements of the steam engine in 1775. Nevertheless, with Fulton's demonstration in 1807, the steamboat industry blossomed. By 1819, a steamboat had sailed from Savannah, Georgia to Russia. The first all-steam crossing, without the use of supporting sails, occurred in 1827. By the mid 1800s, transatlantic steamboat lines were competing.

The first reported self-propelled steam land vehicle was in the late 1600s and, by the late 1700s, a French-built steam car had been demonstrated in Paris. Soon after, an English built car was demonstrated. The first practical and successful locomotive was built in Britain by John Blenkinsop in 1812. The beginning of the railway industry is usually reported as starting with George Stephenson who created the Stockton and Darlington Railway in Britain which opened in September, 1825. Soon after, it is argued, the railway era really began with the opening of Liverpool and Manchester Railway in Britain in September, 1830. By the 1850s, the railroad's effects on the American economy were pervasive. Uniform methods of construction, grading, and bridging emerged. Much of the design of rails, locomotives, coaches, and freight cars was close to what we have today, at least in terms of appearance.

The first true automobile was designed by Frenchman Nicolas-Joseph Cugnot in 1769. This automobile was a steam-powered tricycle and was capable of 2.25 mph for 20 minutes. Germans Carl Benz and Gottlieb Daimler are credited with the first gasoline-engine automobile in 1885. In the U.S., George Selden filed a patent for the automobile in 1879. Charles and Frank Duryea created an American gas-powered automobile in 1892–93. By 1898, there were 50 automobile companies. Between 1904 and 1908, 241 automobile companies went into business. Interestingly, steam propulsion retained a dominant position for quite some time – at the turn of the century, 40% of U.S. automobiles were powered by steam, 38% by electricity, and 22% by gasoline.

Serious speculation about flight occupied such thinkers as Roger Bacon in the 13th century and Leonardo da Vinci in the 15th century. After a wealth of attempts over several centuries, Orville Wright, in 1903, flew for 12 seconds and landed without damage. In 1914 the Census Bureau listed 16 firms as aircraft manufacturers with combined total output for the year of 49 planes. By 1918, the American aircraft industry was delivering 14,000 aircraft with 175,000 employees. However, after the signing of the World War I armistice, production dropped to 263 in 1922.

Commercial aviation eventually diminished the dominance of military customers in the aircraft market. Until the late 1950s, over half of the commercial aircraft in the world were built by Douglas, having continually built upon the success of the DC-3. However, Boeing quickly moved into jet aircraft, mostly due to military contracts. Using the military KC-135 as a starting point, Boeing introduced the 707 commercial transport in 1958. Douglas was much slower to shift paradigms. Boeing's "bet" on jet aircraft provided the basis for its strong position in commercial aviation today.

The patterns of innovation just outlined for steamboats, trains, automobiles, and trains are closely linked to propulsion – steam, internal combustion, and jet engines. Combined with inventions in mechanical systems, aeronautics, and manufacturing – including many, many inventions that never gained broad acceptance – these patterns moved us faster and higher, both literally and economically.

## Innovations in computing

The evolution of computer technology and the computer industry took hundreds of years. The first mechanical adding machine was built more than 300 years ago by Frenchman Blaise Pascal. German Gottfried Wilhelm Liebniz, after seeing Pascal's machine, created the Stepped Reckoner in 1673. Charles Babbage conceived the first digital computer in the 1830s. He envisioned this computer — the Analytical Engine — as powered by steam which, as noted in the last example, was "high tech" in the 1830s.

Babbage got his idea for a digital computer from Frenchman Joseph-Marie Jacquard's punch-card programmed looms, developed in the early 1800s. Jacquard's punched card method for controlling looms also influenced American Herman Hollerith who invented a card-based system for tabulating the results of the 1890 census. Hollerith's venture led to what would later become IBM.

During the latter half of the 19$^{th}$ century and first half of the 20$^{th}$ century, IBM, NCR, Burroughs, Remington Rand, and other companies became dominant in the business equipment industry with tabulators (IBM), cash registers (NCR), calculators (Burroughs), and typewriters (Remington). The dominance of these companies in their respective domains set the stage for their becoming primary players in the computer market.

The emergence of digital computing and the process of maturation of the computer industry starts with John V. Atansoff of Iowa State who built a prototype of an electromechanical digital computer in 1939. By 1946, John W. Mauchly and J. Presper Eckert at the University of Pennsylvania had completed the Electronic Numerical Integrator and Calculator, ENIAC, which was the first all-purpose, all-electronic digital computer and led to Remington-Rand's UNIVAC.

Remington-Rand had some early success including selling UNIVAC machines to the Census Bureau, which displaced IBM tabulators. However, IBM eventually beat out Remington-Rand because IBM recognized the tremendous potential of computers and how they had to be marketed. IBM recognized what was likely to happen in the business machines industry and responded by developing a customer-oriented strategy that helped their customers to deal successfully with trends that were affecting them.

In the late 1950s and early 1960s, a whole new segment of the computer market emerged – interactive rather than centralized computing. IBM dismissed and then ignored this segment. They apparently could not imagine that customers would want to do their own computing rather than have IBM support and possibly staff a centralized computing function. Later IBM tried to catch up, but did so poorly. By the late 1960s, Digital Equipment Corporation (DEC) dominated interactive computing with their minicomputers.

By the late 1970s, Apple was putting the finishing touches on the first microcomputer which would spark a new industry. DEC, in a classic business oversight, failed to take interactive computing to the next logical step of personal computing. Apple, exploiting the aforementioned pioneering inventions at Xerox, created the Macintosh in the mid 1980s. The Mac became the industry standard, at least in the sense that its features and benefits were adopted throughout the personal computer industry. Microsoft and Intel were the primary beneficiaries of this innovation.

Microsoft prospered when IBM chose them to create the operating system software — DOS — for IBM's personal computer. DOS soon became the industry standard, except for Apple enthusiasts. Microsoft Windows replaced DOS as the standard. With the introduction of Windows, Microsoft was able to create software applications for word processing, spreadsheets, presentations, and databases and now controls these markets.

Now, of course, the Internet is dominating attention. Microsoft is battling with a range of competitors, hoping to transform a variety of inventions into dominant market innovations. The rules of the game have changed substantially as this industry has moved from mainframe to mini to micro and now Internet. Most inventions will not become innovations, but certainly a few will.

The patterns of innovation in computing revolve around power and speed. More and more computing operations, faster and faster, differentiate the mainframe, mini, and micro eras. Increasing user control has also been an element of these patterns, although this has resulted with increasing numbers of layers between users and computation. Further, it has been argued that pervasive networking is only possible with increased centralized control of standards, protocols, etc. (Rochlin, 1997). Thus, the latest pattern of innovation may inherently borrow from old patterns.

## Innovations in jazz

Louis Armstrong, with his trumpet, brought jazz into the modern era. Arriving in Chicago from New Orleans in the early 1920s, he was a pioneer of "hot jazz" with a new tempo and sound (Crumpacker & Crumpacker, 1995; Sudhalter, 1999). Armstrong was also known for his vocal creativity in scat singing where the voice is used to mimic a musical instrument.

Hot jazz transitioned to "swing" in the mid 1930s. Swing involved much larger ensembles, highlighted by dancing which led to great popularity. Duke Ellington, with his breath of experimentation and accomplishment, is generally viewed as the leading innovator of this period (Crumpacker & Crumpacker, 1995; Stearns, 1956), although Count Basie, Benny Goodman, and Artie Shaw are also well recognized (Sudhalter, 1999). In contrast to hot jazz, this era has been characterized as "big jazz" (Lees, 1988)

Bop or bebop emerged in the late 1940s, as a reaction to jazz musicians feeling they were becoming old fashioned. This led to "cool" jazz, as a reaction to earlier "hot" jazz, with behaviors such as musicians turning their backs to audience while playing (Stearns, 1956). Dizzy Gillespie, on the trumpet, and Charlie Parker on the saxophone, led this movement with changes of scales and cords combined with a driving style, shattering previous boundaries (Crumpacker & Crumpacker, 1995).

Miles Davis, who earned his early reputation as a bebop and cool jazz trumpeter, led jazz to new directions (Crumpacker & Crumpacker, 1995). *Kind of Blue*, released by Columbia Records in 1959, became the best-selling jazz recording ever and still continues to sell well. In *Kind of Blue*, Davis collaborated with pianist Bill Evans (Petttinger, 1998) to introduce modal jazz, moving from an emphasis on chords to scales and dispensing with bebop's profusion of notes to use fewer notes and make them matter more (Kahn, 2000). Davis went on to cross the boundaries from jazz to pop to create "fusion," best exemplified by his success with *Bitches Brew*.

Thus, these streams of innovation in jazz began with hot jazz, moved to big jazz (swing), then to cool jazz (bebop), and on to modal jazz and fusion. With each movement, the rules of the game changed – the patterns on the sheet were different. However, there were rules. An absence of rules, such as pursued by recent attempts at "free jazz," has hindered innovation, some have argued, precisely because of this lack.

### Innovations in modern painting

The revolt of the Impressionist painters set the stage for modern painting. Rejecting the sentimentality and rigidity of hundreds of years of realist tradition, the Impressionists painted the fleeting moment, capturing their subjects – people and nature – as they were with vivid colors and brushstrokes. They captured light with their paints, and unabashedly celebrated the dashes of paint themselves (Keller, 1975).

Eduoard Manet was perhaps the first Impressionist, shocking audiences with the reality of picnics and courtesans in the mid 1860s. Camille Pissarro was the pure landscapist. Claude Monet perfected the breakup of light and color that epitomized the Impressionist style (Gordon & Forge, 1983). Pierre-Auguste Renoir, Edgar Degas, and Henri de Toulouse--Lautrec were also major Impressionists.

The Impressionists provided a technical point of departure for Georges Seurat, Paul Gauguin, Vincent van Gogh, and Paul Cezanne, collectively called the Post-Impressionists – or perhaps the Pre-Modernists – in the late 19$^{th}$ century. They no longer constrained themselves by realistic conceptions of art. They delved into the subjective and emotional, not just of their subjects but of themselves.

Seurat with his Pointillism combined the Impressionists' techniques with color theory of relationships between emotions and hues to create chromatic tour de forces. Gauguin created color and line images of his personal dreams. Van Gogh strove to "console humanity" with his colorful portrayals of emotion (Walther & Metzger, 1993). Cezanne could see nature as composed purely of cylinders, spheres, and cones, thereby anticipating Cubism.

Early in the 20th century Pablo Picasso and Georges Braque pioneered Cubism, decomposing three-dimensional forms into flat areas of pattern and color, overlapping and interlacing shape and parts of the form so that they are seen from multiple perspectives at the same time. They completely rejected being constrained to imitate nature. The rules of the Cubist game were constraining in themselves, however, leading to numerous offshoots and variations.

In a similar time period, Fauvism emerged in which the elements of the subject of a painting become a riot of colors. Henri Matisse is perhaps the best-known painter in this movement (Elderfield, 1996). He claimed that his works aimed to discover the essential character of things beneath their superficial appearance.

Surrealism came on the scene after World War I, most notably with the works of Salvador Dali, Joan Miro, Rene Magritte, and Max Ernst. These painters sought to create explorations of the unconscious mind, merging dreams, fantasy, and reality. With its emphasis on content, Surrealism provided a counterpoint to the very formalistic Cubism.

Many other "isms" have flourished in modern painting, e.g., Expressionism. All of these movements invented new rules and thereby new patterns associated with subjects, form, color, texture, etc. As these rules were explored, accepted, and elaborated by painters beyond the originators, these movements became innovations in modern painting, bringing fundamental change and moving the whole endeavor forward.

## Summary

Discovery and invention of new patterns, some of which become more broadly accepted to become innovations, are pervasive in these four examples. The abilities of creative and motivated people to see new connections and distinctions underlie these many instances of invention and innovation. Thus, the common threads across technology and art are quite apparent.

## Conclusions

Despite the common threads, there are a few differences that are quite important. One of these differences concerns the simple fact that innovative patterns in art persist, while innovative patterns in technology are eventually replaced or at least disappear from view. Classic technology primarily persists by becoming art. It is appreciated, perhaps enjoyed, but no longer used.

This important distinction serves to emphasize differences in the intentions of technologists and artists. Beyond common behavioral and social underpinnings, technologists are trying to solve problems and satisfy markets while artists are trying to express essential realities of human experience. Technologists and artists have much in common, but not everything.

Another important difference concerns the scope of innovations in technology and art. Most of the technological innovations discussed earlier were attributed to organizations, while most of the artistic innovations were attributed to individuals. Technology innovations often draw upon the inventiveness of many people. However, they seldom sign their creations. Clearly, the social and economic rules of the overall game are quite different in these two domains.

Nevertheless, the fundamental conclusion of this essay is that invention and innovation, as psychological and social processes, are quite similar across domains of human endeavor. Perhaps, we can conclude that we all simultaneously reflect aspects of the technologist and the artist. More modestly, we can certainly conclude that learning and exercising creativity – being inventive and, if persistent and lucky, occasionally innovative – are quite the same regardless of the domains we pursue.

## References


Alexander, C. (1964). Notes on the synthesis of form. Cambridge, MA: Harvard University Press

Alexander, C., Ishikawa, S., Silverstein, M., Jacobsen, M. Fiksdahl-King, I., & Angel, S. (1977). A pattern language: Towns, buildings, construction. New York: Oxford University Press

Borchers, J. O. (2001). Designing interactive music systems: A pattern approach. Linz, Austria: University of Linz, Telecooperation Research Group

Brinkman, W. F. (2000, March 20). Why Bell Labs sticks to the basics. Business Week, pp. 18F–H

Burke, J. (1996). The pinball effect: How Renaissance water gardens made the carburetor possible and other journeys through knowledge. Boston: Little, Brown

Christensen, C. M. (1997). The innovator's dilemma: When new technologies cause great firms to fail. Boston: Harvard Business School Press

Crumpacker, B., & Crumpacker, C. (1995). Jazz legends. Layton, UT: Gibbs Smith

Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience. New York: HarperCollins

Economist. (1999, Dec 4). Fear of the unknown. The Economist, pp. 61–62

Elderfield, J. (1996). Henri Matisse: Masterworks from the Museum of Modern Art. New York: Museum of Modern Art

Gordon, R., & Forge, A. (1983). Monet. New York: Harry Abrams
Heilmeier, G.H. (2000, May–June). Enabling innovation the "no excuses" way. Research Technology Management, 43 (3), p. 26
Kahn, A. (2000). Kind of Blue: The making of the Miles Davis masterpiece. New York: Da Capo Press
Keller, H. (1975). The great book of French Impressionism. New York: Hudson Hills Press
Lees, G. (1988). Meet me at Jim & Andy's: Jazz Musicians and their world. New York: Oxford University Press
Mokyr, J. (1990). The lever of riches: Technological creativity and economic progress. New York: Oxford University Press
Pettinger, P. (1998). Bill Evans: How my heart sings. New Haven, CT: Yale University Press
Rochlin, G. I. (1997). Trapped in the net: The unanticipated consequences of computerization. Princeton, NJ: Princeton University Press
Rouse, W. B. (1986). A note on the nature of creativity in engineering: Implications for supporting system design. Information Processing and Management, 22 (4), pp. 279–285
Rouse, W. B. (1992). Strategies for innovation: Creating successful products, systems, and organizations. New York: Wiley
Rouse, W. B. (1996) Start where you are: Matching your strategy to your marketplace. San Francisco, CA: Jossey–Bass
Rouse, W. B. (2001). Essential challenges of strategic management. New York: John Wiley
Salingaros, N. A. (2000). The structure of pattern languages. Architectural Research Quarterly, 4, pp. 149–161
Smith, D. K., & Alexander, R. C. (1988). Fumbling the future: How Xerox invented, then ignored, the first personal computer. New York: Morrow
Snow, C. P. (1965). The two cultures: And a second look. Cambridge, UK: Cambridge University Press
Stearns, M. W. (1956). The story of jazz. New York: Oxford University Press
Sudhalter, R. M. (1999). Lost chords: White musicians and their contributions to jazz: 1915–1945. New York: Oxford University Press
Walther, I. F., & Metzger, R. (1993). Vincent van Gogh: The complete paintings. Köln: Benedikt Taschen

# Advanced Interaction Media as a Component of Everyday Life for the Coming Generation[1]

*Guy Boy*

## Abstract

The information society has become an economic reality. Advanced Interaction Media (AIM) are an integrating part of our every day life. They enable people to interact with various types of databases, i.e., credit card machines, as well as with other people, i.e., email. Knowledge management is key in our changing society where people are provided with much more information than before. AIM have two apparently opposite properties such as dematerializing the relations to things, e.g., credit card machines enable people to handle business without using bank notes, and materializing the relations to things, e.g., email enables people to communicate even when they don't interact in the same location and at the same time. These machines perform many of the routine tasks that were allocated to humans. However, since it is difficult to design machines that can handle unexpected situations, human will need to remain in the control loop. This paper addresses new issues on interaction with intelligent agents, human and / or machines. In particular, problems like cooperation, communication, and education are discussed.

[1] A first (quite different) version of this paper was presented for the Dialexis Company in December 1991 at the JMA Marketing World Congress in Tokyo, Japan, when the author was the President of Dialexis S.A., France. It was initially written when he was the Leader of the Advanced Interaction Media Group at NASA Ames Research Center, California, U.S.A.

## Introduction

The information society is an economic reality. Television, e–mail, the Web, and e–commerce are some of the visible traits of the information revolution. In particular, they allow exchange of information from remote places that were hardly accessible before. A deeper transformation of our societies is ongoing.

*"We are indeed in the stages of a major technological transformation, one that is far more sweeping than the most ecstatic of the futurologists yet realize, greater even than Megatrends or Future Shock. Three hundred years of technology came to an end after World War II. During those three centuries the model for technology was a mechanical one: the events that go on inside a star such as the sun … Since the end of World War II, however, the model of technology has become the biological process, the events inside an organism. And in an organism, processes are not organized around energy in the physicist's meaning of the term. They are organized around information" (Drucker, 1985).*

Generally, when speaking about information science, we already have in mind computer science as a logical support. The reality is that current products and trends in information transfer and processing are superseding conventional computer products. These new products include, for example, electronic publishing (i.e., electronic books and self-personalizing electronic newspapers, magazines and television broadcasts). Advanced techniques are being used to improve the quality of communication, e.g., advanced television research, real-time computer animation, movies of the future (3D special effects and computer-generated pictures), computer games, visual design, speech recognition, Web technology, computer music, research on the psychological and sociological aspects of computers in schools. Such *Advanced Interaction Media (AIM)* are becoming part of our technological civilizations.

Air traffic control systems, various kinds of cockpits and control rooms, and office automation tools are already-established examples of AIM. In this paper, I consider that AIM are based on different kinds of approaches and technology such as human-computer interaction (HCI) and artificial intelligence (AI). In particular, AIM supported the development of HCI research and development for the last two decades. HCI and AI developed different perspectives that could be partially summarized in the debate opposing direct manipulation to agent technology. On the one hand, computers are used to ease interaction, with complex systems in particular. On the other hand, computers are used to delegate complex tasks to the machine. An appropriate combination of these approaches leads to the design of intelligent assistant systems (IAS: Boy, 1991).

Cognitive engineering has grown from the need to better understand human-centered design of information-intensive systems such as new generation aircraft cockpits. In an aircraft cockpit, a human copilot shares the work, but not the ultimate responsibility, with the captain. The captain is the master on board: he may consult his copilot whenever he likes during the flight but will take the ultimate decisions. If the captain delegates a part of his responsibility to the copilot, then the copilot will take this delegation as a task to be executed. In addition, the captain may, at any time, choose to stop the execution of a task by the

Guy Boy: I met Gunnar in the early eighties when I started my post graduate studies. After my PhD in Automation and Computer Science, I started to study psychology. This was the period I started at NASA in the United States. I had the great opportunity to meet with Gunnar during a workshop organized at Ispra, Italy. This workshop on cognitive engineering in complex systems was the basis of a book and a special issue of the International Journal of Man Machine Studies. After that I started to organize the series of conferences called International Conference on Human-Machine Interaction and Artificial Intelligence in Aerospace (HMI-AI-AS) that led to the current HCI-Aero conferences. Gunnar participated in a couple of these conferences organized in Toulouse, France. We met again when we were involved in the FANSTIC European project where we proposed models of human pilots and cognitive methods to analyze and assess Air Traffic Management. We also were involved, during three years, together in the RoHMI (Robust Human-Machine Interaction) network of Excellence funded by the European Commission. We co-supervized the PhD work of Markus Durstewitz who produced a remarkable thesis that is an example of a successful French-German scientific and technical cooperation. I always had intense and productive working relationships with Professor Johannsen, and at the same time a great human relationship with my friend Gunnar.

copilot, if he judges this to be necessary. However, a copilot may have personal initiatives, for example, testing parameters, keeping current with the evolving situation and predicting deducible faults. A copilot may process the knowledge included in the operation manual, on his own initiative or at the request of the captain. He should be capable of explaining, in an appropriate amount of detail, the results of his processing (Boy, 1991).

Advanced human–computer interaction should be designed according to the principles that emerge from the above description of what a human copilot is about. People now interact with cognitive artifacts that have social affordances. The analysis of the concept of social affordances leads to a functional view of human cognition. Cognitive functions that are useful for the use of artifacts are defined along with three attributes: a role, a context of validity, and a set of resources (Boy, 1998). Cognitive function allocation among human and machine agents is a key issue that leads to the definition of co-relability of human and machine agents in terms of co-operation, co-adaptation, co-dependency and situation awareness. The cognitive function analysis (CFA: Boy, 1998) was developed to cope with cognitive function allocation and congruence. Advanced interaction media are incrementally designed and refined by a series of usability and usefulness evaluations. CFA is being used to rationalize these evaluations.

This paper presents an approach to better understand the evolution of AIM going from what the aerospace brought to what computers can bring, and the integration of software technology in our everyday lives. Since information transfer and processing has become crucial today, technology such as teleconferencing, email, computer integrated documentation and computer-supported cooperative work are analyzed in the framework of the emerging Web technology. Finally, I conclude on the organizational evolution from army to orchestra.

## A Glance at Our Socio-Technical Evolution

A general trend in our technological society is that automation transforms painful jobs into easier, even boring, jobs. We also start to notice that this transformation of jobs introduces a new factor: the unanticipated failure that is very difficult to diagnose and repair. This evolution "from pain to failure" is a no-end automation process, i.e., even if we can design an automated system that will detect and repair failures, we will have to design another automated system that will detect and repair failures on it. It would be wishful thinking to imagine that we can design complex systems that never fail. We thus have to accept the fact that human beings will stay in control to detect and repair failures. One solution would be to say: "thus let's design simple systems!" Simplicity is a goal that is never easy to achieve.

Based on past experience, there is every reason to expect that automation will keep increasing in the coming decades. In particular, intelligent assistance will become more and more sophisticated, with increased *autonomy sharing* between human operators and assistant systems. The idea of a multi-facet artificial copilot in an aircraft cockpit has become a reality with the integration of autoflight modes, flight management systems, collision avoidance systems, and enhanced situation awareness systems for example. It is thus very important to address the problem of human-centered automation, for better understanding of triangular interactions (system being controlled – human operators – assistant systems) and for implementing suitable information technology.

## The Aviation Experience

An important data source on real-world information transfer problems is the Aviation Safety Reporting System (ASRS) which has been in operation at NASA Ames Research Center since 1976 (Billings, 1981). We here mention early results presented in 1981 and based on 28,000 reports from flights occurring during the period 1976–1981. These confidential reports were submitted by pilots and air traffic controllers. Nearly 70% of the reports mention information transfer problems, primarily problems in verbal communication, but there are also many examples of poor transfer of visual information. Even if technology has greatly improved during the last two decades, these issues are still relevant today. Most of the information on which the safety and efficiency of aviation operations depends is highly dynamic. Neither pilots nor controllers can make adequate decisions without clear and sufficient information. Deficiencies in information transfer therefore have direct safety implications. These deficiencies can be attributed to the poor definition of interface filters, inadequate design of machine agents, and sometimes to inappropriate training of personnel. It should be noted that analyses of subsequent data reinforced these results.

Information has two necessary conditions: existence and availability. The first condition involves the emitter of the information and perhaps an on-board receiving instrument in the cockpit. The second condition involves the human receiver of the information. Information must be available at the right time for the person who needs it. Many information transfer problems are attributable to the inadequacy of the message transmitted and to its occurrence at an inappropriate moment.

## What are Computers able to do?

Accidents in commercial aviation and in nuclear power plants have demonstrated dramatically the extent to which excessive automation can lead to a decrease in the vigilance of human operators. Moreover, it has been shown that when human operators act, they are excellent at surveillance and supervision. Automation has then to be designed in order to improve the overall performance of the resulting human-machine system by keeping human operators in control. Computers are good at monitoring independent subsystems, presenting goals and causal explanations to the human operator, and implementing simple simulations based on rules, such as diagnosis and scheduling tools. Such software tools implement standard procedures and are unable of any imagination or creativity. They are systematic. This is their strength and weakness at the same time. They are stronger than people because they are more reliable for the task that they are design to accomplish in a limited context of use. The reliability of safety-critical computer systems is currently very high compared to human reliability. They are weaker than people because they are unable to create new solutions in unexpected situations.

## Towards the Abolition of the Computer Myth

Ten years ago, computers were still a myth for most people who did not understand what they were for. Today, computers are being used to create new ideas by using text processing and new communication means such as email and the Web, for example. Paul Heckel (1984) mentioned that:

> *"Movies did not flourish until the engineers lost control to artists—or more precisely, to the communications craftsmen. The same thing is happening now with personal computers."*

Donald Norman wrote in his foreword to Brenda Laurel's book (1991):

> *"It is time for engineers to go back to engineering. To develop these new technologies, we need a new breed of creative individuals, most likely those associated with poetry, writing, and theatrical direction."*

We could add marketing and organization specialists to this list.

A question remains however: will computers keep their status as tools for specialists? They are more and more integrated into appliances. Computers are becoming invisible (Norman, 1999), i.e., integrated into our everyday life. User-centered design of these appliances is the key issue. Software should not be developed by engineers for engineers anymore. A smart software application is not a complex piece of code that specialists can only admire. It is a tool that people can use without noticing it. For most people, the goal is to enjoy the music not the engineering of the instrument for example. We think that the evolution of computer technology will force us to take a wider, broader perspective on the nature of human activity. Technology can improve our experience and fun only if we use it in a proper way. In this view, computers will become new media routinely used by everyone around the world to exchange and process information. Brenda Laurel (1991) shares this idea when she claims that we should *"Think of the computer not as a tool, but as a medium."*

## Information Transfer and Processing

### Teleconferencing

The process of information exchange and group meetings of professionals involves a great deal of physical energy if we look at it from the point of view of people gathering. First, professionals who do not generally work in the same area have to commute when they need to meet. Another way of gathering professionals is to use teleconferencing systems that are available nearby your work place. In the current systems, for instance, you see the person you are talking to on one part of the screen, and other materials such as handouts on the other part.

If current teleconferencing systems are useful, the next generation will be even more so. It will very probably include electronic meeting systems (EMS) to support group work. EMS will abolish the notion of physical distance between people. Furthermore, EMS should progressively become a new form of meeting environment. J. F. Nunamaker et al. (1991) argued that

*"EMS facilitates group work in many situations because it:*

- *enables all participants to work simultaneously (human parallel processing);*
- *provides an equal opportunity for participation;*
- *discourages behavior that can negatively impact meeting productivity;*
- *enables larger group meetings which can effectively bring more information, knowledge, and skills to bear on the task;*
- *permits the group to choose from a spectrum of structured or unstructured techniques and methods to perform the task;*
- *offers access to external information; and*
- *supports the development of an organizational memory from meeting to meting."*

### Electronic Mail

Information access has become very critical during the last decades, it will be crucial in the next century. In his recent book about the Massachusetts Institute of Technology (MIT) Media Laboratory, Stewart Brand (1988) wrote:

*"A personal computer without a telephone line attached to it is a poor lonely thing. So far about a quarter of the 10 million computers in American homes have plugged into the phone system and tied into electronic mail ('e-mail'), computers teleconferences, and online databases. Even more of the same thing is going on in offices, where e-mail is becoming a way of life in some businesses."*

E-mail provides an incredibly communicative medium that is currently used to exchange quick information between remote places distributed all over the world. Every morning, the first thing I do is reading my 10 to 20 messages that are waiting in my mail box. This is actually a major problem when you start to allow non-personal (non-private) e-mail to reach your mail box. Subscribing to too many bulletin boards can be very overwhelming. Intelligent assistants such as information filters decide what kind of information would be interesting to you.

French people have experienced the Minitel (personal electronic phone books) for more than 15 years. Minitel turned out to be exceptionally successful. People do their shopping, banking, hotel and airline reservations at home using Minitel. Today, the Web is replacing the Minitel as a world-wide communication and documentation tool. Personal computers are sold with integrated communication capabilities. The main idea is to communicate with others using natural (i.e., non-obstructive and / or painful) media. These media should allow remote transmission and not distort intentions, questions, needs, feelings and acknowledgements, for example.

## Computer Integrated Documentation

Everyone recognizes that text and graphics are common media for transmission of knowledge between people. In large organizations, such as NASA, an enormous number of documents are produced to transfer knowledge from designers to manufacturers, or from manufacturers to operations people, for instance. These documents are generally paper-based.

Documentation is very labor-intensive, requiring a great deal of expertise and development time. One significant problem that interests us is that expert developers may no longer be available by the time a very large documentation project is nearing completion. If a user needs help from documentation developers, they may have been assigned to a different project or changed employment. In the former case, they have to carry out a tremendous amount of problem solving activity to understand and retrieve the information needed by the user. In the latter case, the user usually does not try to go further in the documentation. An important question is: how can we capture knowledge in a way that it will be useful for users in the future? Hypertext (Conklin, 1987) provides a technology for incremental annotation, this is part of the answer to that question. Hypermedia is an extension of hypertext that incorporates other media as well as text, such as graphics, animations and sound (Yankelovich et al., 1988).

The Computer Integrated Documentation (CID) system developed at NASA Ames Research Center is a hypermedia system that allows users to share hierarchies of documents of different forms, retrieve information stored in them, and add personal annotations (Boy, 1991). CID provides an intelligent interface for browsing large documents. Sharing information is a complex task. It depends on context, i.e., when someone writes a report, draws a picture, or tells a story, he / she does it within a given context. Readers, watchers or listeners do not necessarily share the same context as people who have generated documents. This is usually a source of misunderstanding. One of the main questions is: how to capture context when documents are generated? Even if this is still a research topic, the ability of CID to automatically acquire the context in which strategies are appropriate is significant. First, it allows the system to provide a tailorable browsing facility. Indeed, the system will learn which referents are to be presented for which user. Second, it shows that it is feasible to immediately incorporate the user's feedback into the system's knowledge, with the possibility of improving the system's performance. In this way, there is no need to collect and analyze large amounts of information about how users interact with the system because the system performs this task itself. Third, with CID we are explicitly specifying a systematic domain (Winograd and Flores, 1987), i.e., development and use of technical documentation. To paraphrase Winograd and Flores, the impact of CID comes not because the programs it includes are "smart" but because it allows people to operate effectively in a systematic domain that is relevant to human work.

The CID approach can be extended to include television documents. The concept of videotaped documents that can be accessed and processed on a "personal" television can be seen as a computerized extension of present videocassette recorders (VCR). Stewart Brand reported a very interesting statement by Media Lab scientist Alan Kay:

> *"The only way I will watch TV is if it's been videotaped. I haven't watched live TV in years, except for football games, which I don't care about. I want to be able to do all the things I do when I read – I want to be able to stop, to go back, I don't want to be taught by it. I find VCRs liberating."*

We can extend this statement by saying that advanced VCRs will include capabilities that are already available in CID, such as context sensitive search, and graphical browsing.

## Computer Supported Cooperative Work

The idea of a computer–enhanced meeting is at least as old as the room developed by Douglas Englebart in 1968. This room was equipped for computer–supported meetings. Several scientists and engineers have developed methods and prototypes in the area of computer supported cooperative work (CSCW). The simplest tool and media of cooperation is the spreadsheet. Using computer spreadsheets people can enter data and immediately see repercussions on other variables dependent on this data. Spreadsheets are almost trivial to program and are widely used by managers. Kum–Yew Lai, Tom Malone, and Keh–Chaing Yu (1990) from MIT developed Object Lens, a spreadsheet for cooperative work. In this system, a personnel folder containing objects corresponding to employees might be viewed as an organizational chart or a list of employees' names and salaries. It is able to send messages and move objects into folders. Actions of the system are triggered by events such as the arrival of a message meeting certain criteria.

Another system called graphical Issue Based Information System (gIBIS) has been developed at the Microelectronics Computers Corporation (MCC) by Jeff Conklin and his team (1988). The IBIS method establishes a framework for design problems in which design *issues* can be discussed by formulating *positions* that *respond* – to them. Group members state *arguments* which *support* or *object* – to a position.

Recently, Douglas Englebart started the Bootstrap Project at Stanford University (1991). This project is driven by the fact that organizations and individuals are faced with an exploding need to share and manage knowledge more efficiently. "Bootstrapping" describes a strategy for organizational evolution to cope with this need, based on a pragmatic co–evolution of technology and human processes; these processes are both the objects to be improved and the tools we must use to bring about this improvement — thus the bootstrap metaphor. A key technology is to improve the collaboration among widely distributed knowledge workers, helping people in diverse fields (e.g., specialists in design, manufacturing, management, marketing, etc.) to work more easily and efficiently as groups.

The CSCW community developed during the 1990's within the ACM–SIGCHI framework. Olson and Olson (1997) provide an excellent review on CSCW research. Computer scientists, human factors specialists and anthropologists contributed in the development of computer–based meeting systems, electronic conferencing systems, chat systems, as well as cooperation and coordination tools. The Web technology greatly influenced the evolution of CSCW. Languages such as HTML, XML and JAVA have been designed to support the development of CSCW technology.

Recently, Preece (2000) introduced new issues on on–line communities:

> *"Internet communities are here! In fact, they're everywhere. From New York to London, Singapore and beyond, trillions of messages bounce from screen to screen, every second of every day."*

She insists on sociability and usability. Sociability is concerned with issues such as "the goals and roles of the individuals in a community, and policies generated to shape interaction [that] all influence social interaction in the community." Usability is typically concerned with developing computer systems to support rapid learning, high skill retention, and low error rates (Preece et al., 1993, 1994, 2000; Nielsen, 1993, 2000).

## A New Road for Education

Computers can enhance education if they are used appropriately. Exploration of video databases (VDB) for instance can be fun and really educational. During his invited talk at the 1990 conference of the Cognitive Science Society, Roger Schank insisted on the fact that *"thinking means analyzing events so that they become stories and creating indices to* *retrieve stories."* For him, *"intelligence is telling the right story at the right time."* On one hand, education is not linear, i.e., learning by turning pages. On the other hand, discovery has to be guided by a real purpose. Nicholas Negroponte, who is the founder and director of the Media Laboratory at MIT, said (Brand, 1988):

> *"There are children who are registered as 'learning-disabled' who are in no sense learning-disabled at all. Their cognitive style just doesn't fit the method of teaching or the way schools are run. It's tragic, because some very creative children are then literally disabled for the rest of their lives."*

Use of VDB allows learning by doing which enhances remembering. That does not mean that we have to use exclusively the computer to learn. On one hand, it is easier to learn by doing when a good teacher is nearby. On the other hand, human communication and knowledge (especially common sense) will always be necessary. If a computer is used as a repository of knowledge, a medium to browse into this knowledge, and an intelligent assistant that helps you retrieving the right piece of knowledge at the time, then it will allow people to learn "almost" by themselves. Then, computers tend to individualize learning.

According to this rationale, I developed an approach to the design of software agents for cooperative learning (Boy, 1997). This approach is based on a careful analysis of current education practices, e.g., user needs and cultural constraints, bearing in mind the technological possibilities and goals. I claim that information technology (IT) should be designed to preserve a reasonable continuity with current practice, to facilitate knowledge transfer and access, to show a good cost / benefit ratio, where cost includes financial cost as well as additional workload. In the ACTIDOC environment, active documents are generated and managed using current learning documents improved with a pragmatic layer of appropriate software agents. Such agents for cooperative learning are proposed and discussed using typical examples.

## Discussion

All the approaches and technologies that we have mentioned in section 3 are leading towards the same goals: improve cooperative work, easily retrieve information, improve communication between people, and support education. The major trend is very well summarized by the bootstrap metaphor introduced by Douglas Englebart. By designing and using new machines, people improve communication among themselves, and this better communication then improve the understanding of how to improve the design and use of the machines. Thus, people (i.e., users) are central in this incremental design process. This is a major reason to develop studies and research in the cognitive science area. Understanding human behavior and cognitive mechanisms is crucial, if the goal is to improve communication. Education will play a major role during the next decades, especially because the evolution of our technological society is likely to speed up.

## From Army to Orchestra

Up to now, most people were educated in the expectation of pure hierarchical structures in society. With the evolution of the technological society, especially with the development and use of modern media, people tend to realize that their way of interacting with other has changed. In particular, as information become more available to everyone, hierarchical structures, where most of the information was owned by top management people, are traversed laterally. Electronic mail and Web technology are responsible for a major part of this lateral information flow. The result of this process is that professionals will have to know more about others' knowledge. Knowledge management is a real issue. There is a real need to have a holographic view of the world surrounding our own business. In this sense, we are moving from army to orchestra. To pursue this metaphor, people are evolving from isolated nodes in a hierarchical tree structure to intelligent agents who have their own view on the world and can communicate with others. In an orchestra, musicians know how to play their own instrument, but, even if they do not know how to play another instrument, they share music theory and the overall musical score with the other musicians of the orchestra. In modern companies, for instance, workers share objectives, and work philosophy and practise. They cooperate to achieve global objectives. Similarly to an orchestra, this creates an envelop that gives the style of the company. I claim that advanced interaction media, as described in this paper, will become predominant and constitute a main communication, cooperation and coordination support for the next generation of people.

## Acknowledgements

I dedicate this paper to Gunnar Johannsen who developed very valuable research on human–machine systems for the last three decades. In addition to this mastered professional activity, Gunnar is an excellent musician. He knows better than most people how technology and art influence each other towards harmony.

## References

Boy, G. A. (1991). Intelligent Assistant Systems. Academic Press, London, U.K.

Boy, G. A. (1991). Computer Integrated Documentation. In The Social Creation of Knowledge: Multimedia and Information Technologies in the University, Edward Barrett (Ed.), MIT Press, Cambridge, MA

Boy, G. A. (1997). Software Agents for Cooperative Learning. In Software agents. J. Bradshaw (Ed.). AAAI / MIT Press, Cambridge, MA

Boy, G. A. (1998). Cognitive Function Analysis. Ablex Pubishing Corporation, Greewood

Brand S. (1988). The Media Lab. Inventing the Future at MIT. Penguin Books, New York

Conklin, J. (1987). Hypertext: An Introduction and Survey. Computer, September
Conklin, J. & Begeman, M. L. (1988). gIBIS: A Hypertext Tool for Exploratory Policy Discussion. In Proceedings of the Conference on Computer-Supported Cooperative Work, pp. 141–152
Drucker, P. (1985). Innovation and Entrepreneurship. Harper and Row, New York
Englebart, D. C. (1991). The Bootstrapping Project. Seminar at Stanford University
Heckel, Paul (1984). The Elements of Friendly Software Design. Warner Books, New York
Lai, Kum-Yew, Malone, T. & Yu, Keh-Chaing (1990). Object Lens: A 'Spreadsheet' for Cooperative work. ACM Trans. Off. Inf. Syst. 6, 4, pp. 332–353
Laurel, B. (1991). Computer as Theatre. Addison Wesley, Reading, MA
Nielsen, J. (1993). Usability Engineering. Boston, MA: Academic Press
Nielsen, J. (2000). Designing for Web Usability: The Practice of Simplicity. Indianapolis, IN: New Riders Publishing
Norman, D. A. (1999). The Invisible Computer. The MIT Press. Cambridge, MA.
Nunamaker, J. F., Dennis, A. R., Valacich, J. S., Vogel, D. R. & George, J. F. (1991). Electronic Meeting Systems to Support Group Work. Communications of the ACM, Vol. 34, No. 7, July, pp. 40–61
Olson, G. M. & Olson, J. S. (1997). Research on computer-supported cooperative work. In M. Helander, T. K. Landauer, & P. Prabhu (Eds), Handbook of Human-Computer Interaction (2nd Edition) Amsterdam: Elsevier
Preece, J. (Ed.) (1993). A Guide to usability. Human Factors in Computing. Wokingham, UK: Addison-Wesley
Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S. & Carey, T. (1994). Human-Computer interaction. Wokingham, UK: Addison-Wesley
Preece, J. (2000). Online Communities. Designing Usability, Supporting Sociability. John Wiley, New York
Winograd, T. & Flores, F. (1987). Understanding Computer and Cognition. Addison Wesley, Reading, MA
Yankelovich, N., Smith, K. E., Garrett, L. N. & Meyrowitz, N. (1988). Issues in Designing a Hypermedia Document System. In Aubron, S. & Hooper, K. Interactive Multimedia: Visions of Multimedia for Developers, Educators, & Information Providers. pp. 33–85, Microsoft Press

# Action Interface: A Non–Touch Interface Using Video Captured Image

*Yu Shibuya*


## Abstract

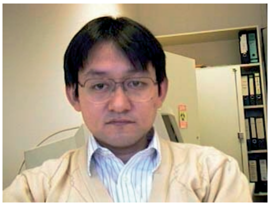
Action Interface, a non–touch interface using video–captured image, is introduced in this paper. It detects user's action with checking the colour of some sensing regions in the video–captured image, and then makes reactions depending on the user's action. Action Interface is easy to configure and has high flexibility so that it is usable and adaptable for various purposes. Some applications using Action Interface are introduced. They are a menu selection system, a virtual musical instrument, a multiuser interaction system, and a presentation support system. As an extension of Action Interface, Action View is also introduced. Action View is an interaction system which detects and tracks user's viewpoint and makes suitable visual feedback to the user. Action View would be usable to look around the large information field through the small display.


## Introduction

In the modern human–machine interaction, some equipments, such as mice or keyboards, are commonly used to point to target or to input commands. In this case, the user should use such equipment, in other words, he / she should adapt him / herself to the machine. However, it might be more comfortable for the user that the machines adapt itself to the human. In such human–machine interaction, the user should operate the machines without any special equipment and he / she directs the machines without any special knowledge about the operation manner. As the new type of human–machine interaction, non–touch interfaces using video captured image have been studied (Segan 2000, Cipolla 1998).

Action Interface is a sort of non–touch interface using video captured image (Shibuya 1999a, Shibuya 1999b). It makes reactions depending on the user's actions or gestures. It detects user's action by checking the colour of some sensing regions located in the video captured image. Since Action Interface is easy to configure and has high flexibility, it is usable and adaptable for various purposes.

In the followings of this paper, firstly, a system configuration of Action Interface and process of detecting user's action are described. Then several applications of Action Interface are introduced. They are a menu selection system, a virtual musical instrument, a multiuser interaction system, and a presentation support system. Furthermore, as an extension of Action Interface, Action View is introduced.



## Action Interface

Yu Shibuya, Dr. Eng., Associate Professor at the Kyoto Institute of Technology, Japan was Guest Researcher at Gunnar Johannsen's Institute during 1997–1998

A basic system configuration of Action Interface is shown in Figure 1. As shown in this figure, the system consists of a video camera and a PC. If the visual feedback image is needed, there should be a display. A user's live body image is captured by the video camera and processed by PC in real time. Depending on the usage, computer graphics are overlapped on the user's body image and they are displayed to the user. PC is also usable to make an auditory feedback to the user or control other devices such as a video camera, a VCR, another PC, and so on.

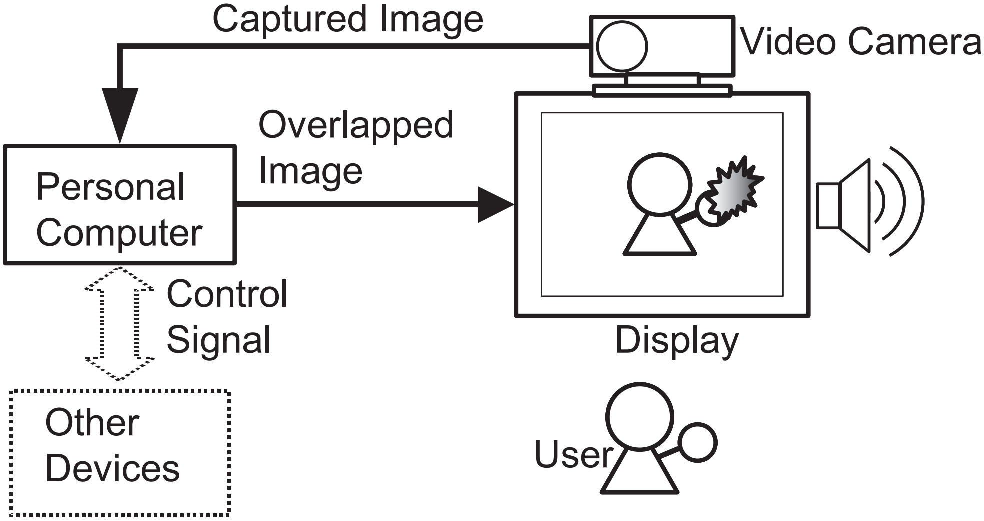



*Figure 1: Basic system configuration of Action Interface*

The system detects a user's action by checking the colour of the sensing region, which is located on the captured image. Two methods are adopted to check the change of colour of the sensing region. One method is to find a predefined colour in each region. For example, supposing that the user's skin colour is measured and stored previously. After that, if the system finds the stored skin colour in the sensing region, the system can recognize that there is the user's hand or face in that sensing region. Another method is to check the difference between current colour of the sensing region and former one. If there is a definite change of colour, the system recognizes that there should be movement such as the user's action. Depending on the purpose or environment, one of above two methods is adopted for detecting the user's action.

In order to detect user's action faster and more accurately, some ideas are introduced into Action Interface:

- Using HSL format for expressing colour instead of RGB format.
- Monitoring only a sensing region not whole part of captured image.
- Using a mosaic image to shorten the image processing time.

When an image is captured by a video camera, colour of each region is expressed in Red, Green, and Blue level respectively. However, RGB colour level changes sensitively depending on the environment. For example, the RGB colour level is dynamically changed depending on the brightness. Such changing of the brightness is often occurred in general environment. In order to avoid such unexpected sensitivity, HSL (Hue, Saturation, Lightness) format is used to express the colour. In this case, if the brightness changes slightly, both saturation and lightness levels change widely but the hue level does not change dramatically. Therefore, in order to monitor the changing of colour, it is better to use HSL format to express colour.

Quick response is important to avoid the user's stress during the interaction with machines. In order to make the image processing faster, monitoring region is restricted to a part of images. Furthermore, before checking the colour changing, captured image resolution was reduced. For example, in current Action Interface, size of a whole captured image is 320–pixels width and 240–pixels height (320x240 pixels). Inside of this image, several sensing regions are set and the image of each region is transferred to mosaic image. Using mosaic is equivalent to reducing the number of pixels of the sensing regions. As a result, it is enough fast to respond to the user's action.

## Applications of Action Interface

In the followings, some applications of Action Interface are introduced.

### Menu Selection

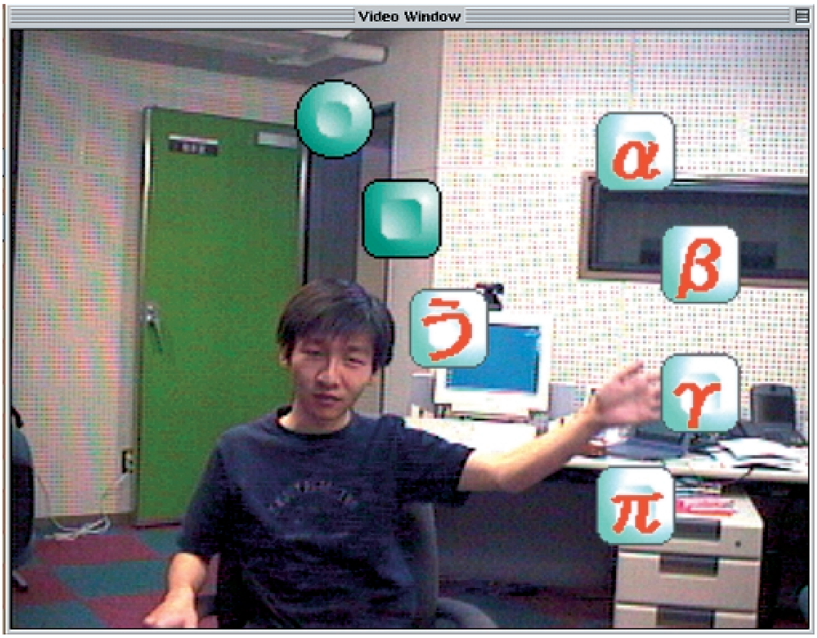
In order to make practical interfaces, it is important to include a menu selecting function in Action Interface. Because of the restriction of the display space, most of menus used in computer desktop system are difficult to use in Action Interface. When the user touches a menu button on the screen, menu items appear surrounding that button. In Action Interface, it is not so good to overlap the menu item on the user's body image so that a quasi–pie menu is adopted.

In usual menu operation, at least two procedures are needed. They are selecting a menu item and deciding that selection. In Action Interface, it is easy to select the menu item on the display by touching one. In order to distinguish the deciding action from the selecting action, a pull–in selection procedure is introduced.

When a user touches the menu button, menu items appear surrounding it and the menu button is changed to the decision button. Then the user selects the desired menu item and that menu item is highlighted. If the user wants to decide the selection, it is simply done by pulling the menu item into the decision button that located at the centre of the quasi–pie menu.

By the way, hierarchical menu is needed for more advanced use. For such purpose, Raijin Menu was introduced. In Raijin Menu, if the user select the menu item which includes further menu items, selected menu item shifts to upper left side and further menu items are appeared on the same position where previous menu items were displayed. Then, if the user selects menu items including further menu items, there happen same procedure as previous case. Until the final selection, such procedure is continued. With this manner of menu selection, Action Interface is usable for hierarchical menu. *Raijin* is the God of thunder in Japan and there are drums surrounding him. The arrangement of those drums is similar with the allocation of the shifted menu item so that this menu was named Raijin Menu (Figure 2).

*Figure 2: A visual feedback image of Raijin Menu*



## Musical Instrument

One of the entertainment uses of Action Interface is to play sound with a virtual musical instrument. In Figure 3, a visual feedback image of the system is shown. In this figure, there are 8 icons on the display. If the user touches one of the icons with his / her hand, assigned sound will be played. The user can touch more then one icon at a time. In such case, a chord will be played.

*Figure 3: A visual feedback image of a virtual musical instrument.*

## Multiuser Interaction System

In order to use Action Interface in the multiuser environment, it is important to distinguish each person from others. That is, the system must identify each person respectively.

The system configuration of multiuser interaction system is shown in Figure 4. The system consists of a video camera, a PC, a video projector, and a rear projection screen. The video camera and the rear projection screen are located in front of the users. Users' body images are captured through the video camera and processed by the PC in real time.

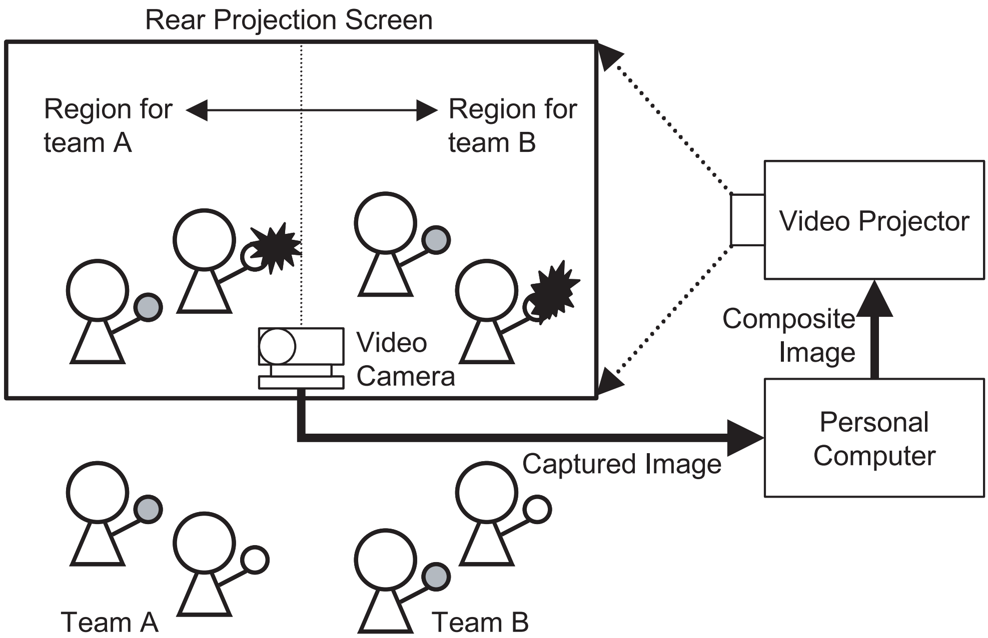



*Figure 4: System configuration of multiuser interaction system using video captured image*

The PC detects each user's action and makes reactions, such as making sounds, changing the colour or shape of visual feedback marks, and so on. The PC is also used for making visual and auditory feedback image to users. CG images are overlapped on the video captured image and the composite video image is projected to the rear projection screen. Users would see their visual feedback image on the screen as if there was a large mirror in front of them.

In order to identify each user, two methods are adopted in this system. In the first method, the video captured image is divided into small regions, and each small region is assigned to each user respectively. The system can identify the user depending on the region where the user's action is happened.

Another method is asking the user to have different coloured goods, e.g., to put on a coloured glove. The system can identify the user by checking the colour.

Furthermore, depending on the purpose, it is suitable to use both methods. For example, when a team game is made using this system, it might be suitable that each team is located at the team region and each member of the team puts on coloured gloves as shown in the Figure 4.

An application of multiuser interaction system has been constructed in our laboratory. The system is a sort of team games, named *Poko Poko 2*. In Figure 5, visual feedback image of *Poko Poko 2* is shown.


*Figure 5: A visual feedback image of* Poko Poko 2, *an application of multiuser interaction system.*

In this application, there are two teams and each team consists of two players. There are many balloons in the display. If a player touches a balloon, the balloon bounces in the general way. That is, the balloon changes the moving direction and speed depending on the player's hand moving. Its shape is changed dynamically when the player touches it. There are needles at both side ends of the display. The balloon bursts when it touches the needles. The purpose of this game is to push the balloon to the competitor's region and to burst 10 balloons in that region as fast as possible.

One team is located at a half region of the display and another team is located at another half region. Each player of the team puts on different coloured gloves. The system can identify the team and player depending on the location of the player and the colour of the glove.

Some experimental uses of *Poko Poko 2* indicated that the user identification methods introduced in this system were useful and enough. The system correctly detected user's action and made reaction in real time.

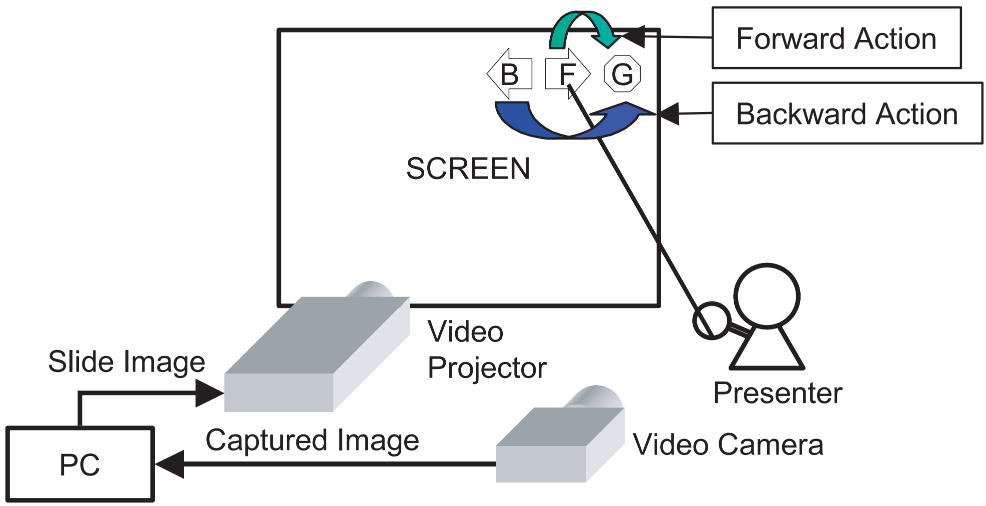
Furthermore, from the subjective evaluation, *Poko Poko 2* was attractive to users. They were enjoying not only to play game but also to make interaction among users. This system might offer a multiuser interaction environment which is useful to stimulate a communication among users.

### Presentation Support

Recently, the combination of PC and projector is commonly used for oral presentation. In such presentation, the presenter must operate his / her PC by him / herself for changing slide, otherwise, he / she must ask someone to change slides. In order to make a presenter to concentrate his / her presentation, Action Point, a presentation support system, is developed.

The system configuration of Action Point is shown in Figure 6 and the scene of presentation using Action Point is shown in Figure 7.

*Figure 6: System configuration of Action Point.*



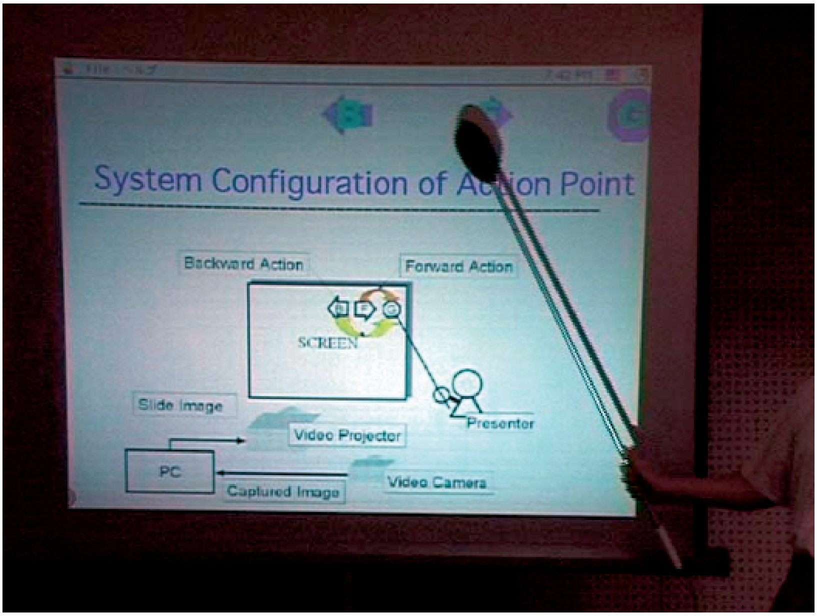



*Figure 7: A scene of presentation using Action Point.*

A presenter can change the slide with simple gesture using Action Point. For example, if the presenter wants to change the slide forward, he / she points to the forward mark on the screen and then points to the decision mark. Then, the system detects his / her action and changes the slide as he / she wants. On the other hand, if the presenter wants to change the slide backward, it is possible by pointing to the backward mark first and moving pointer to the decision mark.

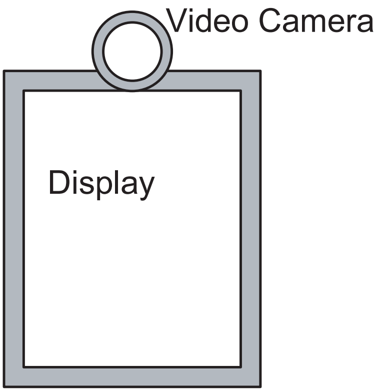
## Action View

Action View is a sort of non-touch interface using video captured image and is aiming to establish the interaction environment in which the user can look around the large information field through the small display. In Action View, the window metaphor is used for the operation manner (Figure 8). For example, when a user stands at the left side of the window he / she can look at the right side of the scene through the window. It is easy to learn and understand how to use Action View because its interaction method depends on the ordinary manner in our daily life. When a user wants to look at his / her desired information with Action View, he / she changes his / her viewpoint. As the result, he / she would be able to look at the information through the display.

*Figure 8: Concept of "window" metaphor.*

Interface of Action View basically consists of a video camera and a display as shown in Figure 9. The video camera captures user's face and is used for detecting the user's viewpoint. Action View tracks user's viewpoint and makes a proper visual feedback on the display.

*Figure 9: Basic interface of Action View.*



In order to find a user's viewpoint, firstly, the system tries to find a face region in the captured video image. The system detects the skin colour regions and checks the shape of them. Some tips are used in this process and, basically, the oval region is adopted as the face region. Then the system tries to find the user's viewpoint. For such purpose, the system checks the brightness along the circle path as shown in Figure 10. In Figure 11, brightness along the circle path is shown. If the circle is on both the user's eyes and eyebrows, the waveform of the brightness will be the particular pattern as shown in Figure 11. After repeated trial and error, finally, the system finds the user's viewpoint as shown in Figure 10. After that, it is not so difficult to track the user's viewpoint because the system can predict the location of user's viewpoint from the history of the movement. Depending on the user's viewpoint, Action View makes a visual feedback.

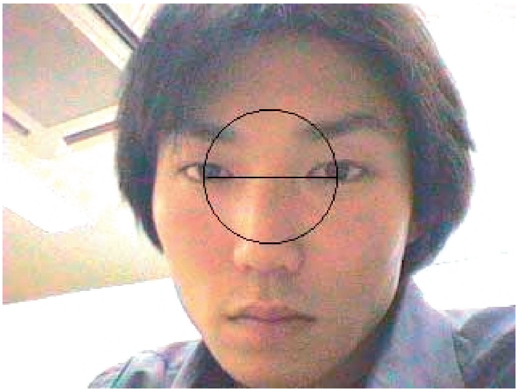
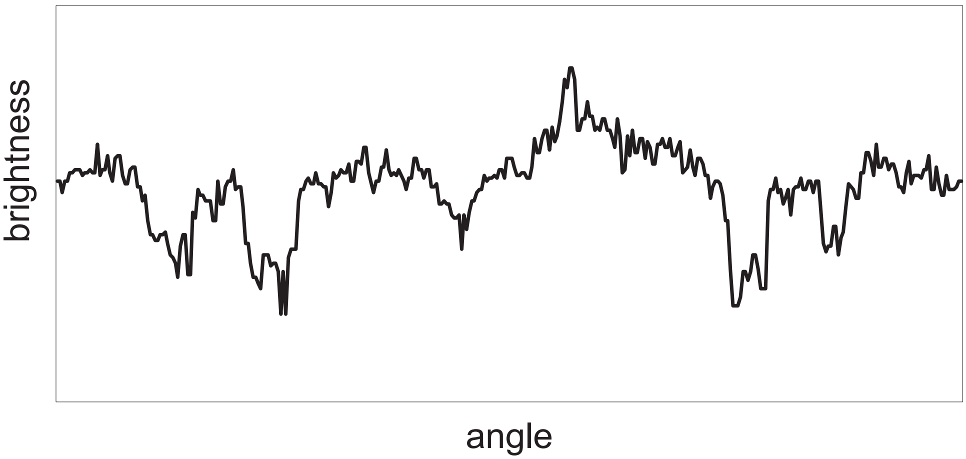


*Figure 10: Viewpoint detection and tracking.*

*Figure 11: A waveform of brightness around user's forehead.*



As applications using Action View, a cellular phone with small display and a character input system are proposed in the followings.

In Figure 12, a design of cellular phone using Action View is illustrated. This cellular phone consists of a video camera, a small LCD, and some numeric buttons. The user can look around the large information field through the baby face interface of cellular phone in intuitive manner. That is, if the user wants to look at the left side of the information field, he / she just changes his / her viewpoint to the right of the display. Such movement is usually done in our daily life. If we want to look around the outside of the room we stand in front of the window and move our viewpoints.

*Figure 12: A design of cellular phone using Action View.*

As another usage of Action View, a character input system is introduced. Recently, cellular phones are broadly used as a kind of PDA (Personal Digital Assistant) for writing or reading email in Japan. Until now, the user inputs characters by numeric key on the cellular phone and reads the email through the small display. It might not be so comfortable for the user. It might be better to use large display and keyboard but there is restriction that the cellular phone should be enough small to be carried with the user.

It is important to develop an effective method to input a character or word using the small equipment. Action View is also usable for Japanese character input method. In Figure 13, a snap shot of selecting a Japanese character on the small display is shown. Japanese characters are located in the matrix style on the sheet. The user tries to find his / her desired character on the display. When he / she changes his / her viewpoint, the sheet of the characters is moved. A character, which is nearest to the centre of the display, is regarded as the current selected character and is emphasised on the display. When the user wants to decide the character, he / she might push a decision button of the cellular phone.

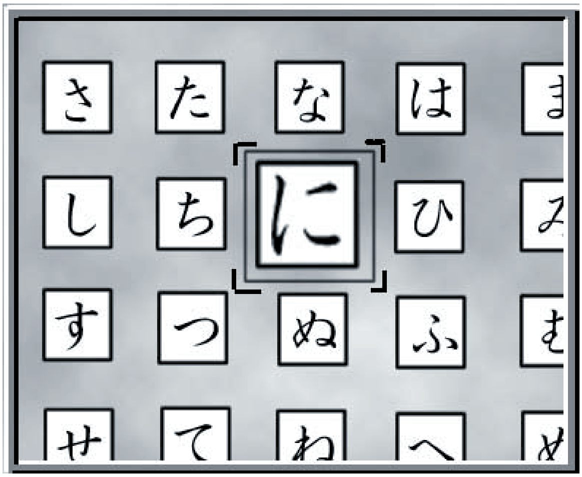



*Figure 13: A Japanese character input system using Action View.*

## Conclusion

In this paper, a sort of non-touch interface, named Action Interface and its some applications were introduced. Furthermore, as an extension of Action Interface, Action View was also introduced. Action Interface has so high flexibility and adaptability that it would be usable for various purposes.

## References

Cipolla, R. and A. Pentland (1998) Computer Vision for Human-Machine Interaction, Cambridge University Press

Segan, J. and S. Kumar (2000) Look ma, no mouse!, Communications of the ACM, 43 (7), pp. 102–110

Shibuya, Y. and H. Tamura (1999a) Interface using video captured images. In: Human-Computer Interaction, Ergonomics and User Interfaces, 1, pp. 247–250

Shibuya, Y., K. Takahashi and H. Tamura (1999b): Introduction of action interface and its experimental uses for device control, performing art, and menu selection, In: Analysis, Design and Evaluation of Man-Machine Systems 1998, pp. 71–76

# An Integrated Method for Model–Based Knowledge Acquisition for Knowledge–Based Diagnosis in Dynamic Systems

*Sabine Borndorff–Eccarius*

## Abstract.

In knowledge acquisition for knowledge–based systems, two different proceedings can be distinguished: the model–based approaches and the rapid prototyping. In this article, the advantages and disadvantages of both types of approaches are described. A new model–based method was developed to lessen the disadvantages of the rapid prototyping and the model–based approaches for developing knowledge–based systems. It integrates three methods: the model–based method of cognitive task analysis, the method of models based on strong problem solving methods, and rapid prototyping. This method can be supported by the interactive knowledge acquisition tool TEMPO with a graphical user interface. It enables the expert to build and to adapt the domain model to the problem solving model of state–based diagnosis. Examples of cases of failure support the expert in reproduction of his or her problem solving behaviour. The generalization of these cases is supported by TEMPO with a learning method. TEMPO considers the temporal aspects of the symptoms and information necessary for diagnosis.

Sabine Borndorff–Eccarius studied computer science at the University of Dortmund. She has worked in the Systems Engineering and Human–Machine Systems Group, led by Prof. Dr.–Ing. Gunnar Johannsen at the University of Kassel, Department of Mechanical Engineering, Institute for Measurement and Automation (IMAT). In the ESPRIT research project „Graphical and Knowledge–based Dialogue for Dynamic Systems" (GRADIENT), she developed and implemented a knowledge–based diagnosis system as a part of the GRADIENT–system. She earned a doctoral degree in engineering from the University of Kassel. Her dissertation focussed on „Computer–Supported Knowledge Acquisition for Knowledge–Based Diagnosis Systems in the Domain of Dynamic Technical Systems." Currently, she is working as an IT–Professional for T–Systems GEI GmbH in Mühlheim, Germany.

## Introduction

Experiences with the development of different kinds of knowledge–based systems for industrial applications have shown that one reason for the failure of knowledge–based systems in practice is that the demands of the tasks are not sufficiently considered (Roth, Woods, 1989). This is often the case, when the rapid prototyping considers only a few examples but not the complete task. Before the necessary knowledge is analysed, the architecture for the knowledge–based system is determined. To reach the design goal in the development of knowledge-based systems, the improvement of the man-machine system, an analysis of the demands of the complete task is necessary.

One of the main problems in building knowledge-based systems is the acquisition of knowledge. On the one hand, the knowledge often exists only implicitly and, therefore, it is difficult to gain. On the other hand, the application domains, in which a knowledge-based system is useful, are complex and need the acquisition of a large amount of knowledge. Two groups of persons are involved in the knowledge acquisition process: knowledge engineers and experts. One of the tasks of the knowledge engineer is to collect knowledge from different sources of knowledge like for instance experts, specialist literature, or other documentation to analyse, interpret, and implement the knowledge. Due to the fact that knowledge engineers have to acquire the knowledge by themselves, before they analyse, interpret, and implement it, communication and transfer failures can arise. Knowledge acquisition is very time-intensive and expensive. Therefore, it is sensible and necessary to improve the effectiveness and quality of the knowledge transfer from the expert to the knowledge-based system.

## Knowledge Acquisition for Knowledge-Based Systems

In knowledge acquisition for knowledge-based systems, two different proceedings can be distinguished: the rapid prototyping and the model-based approaches.

### Rapid Prototyping

In the rapid prototyping approaches, a prototype of the knowledge-based system is built after collecting a relatively small amount of examples of cases. Examples of rapid prototyping approaches are those of Buchanan et.al. (1983), Harmon, King (1989), Freiling (1985) and Grover (1983).

Rapid Prototyping has the following advantages:

- Knowledge engineers and experts can check very fast, if the knowledge transfer was performed correctly.
- The expert can review the assumption about the structure of knowledge and inference strategies, the behaviour of the system, and if knowledge is missing.
- The relative short feedback cycles can be motivating for the expert and management.

Disadvantages of the rapid prototyping are:

- The architecture of a system has to be determined before all the necessary knowledge is collected and analysed.
- Therefore, the interpretation and representation of the knowledge is to a great extent influenced by implementation formalisms.
- The world of terms of the expert is not corresponding to the implementation language of the knowledge bases.
- Changes proving to be necessary later, or extensions of the system's architecture can be costly.

## Model-Based Approaches

The most important difference between the rapid prototyping approaches and the model-based approaches lies in the separation of the interpretation and analysis from the representation of the knowledge. Using the rapid prototyping approaches, the model of expertise results at the end of the development process. In the model-based approaches, first, a model of expertise is built which is independent from the implementation. This model of expertise describes the knowledge on a higher level as the implementation level. Such a model allows a representation in terms of the expert, which types of knowledge are necessary for carrying out a task, and how the knowledge is used for it.

The model-based approaches own the following advantages:

- With the separation of the interpretation and analysis from the implementation, the model has a larger closeness to the world of terms of the expert.
- After the interpretation and analysis phase, a relative complete description of the expertise exists. It can serve as a basis for the specification for the implementation of the knowledge-based system.
- To support the knowledge engineer, generic models can be provided which leads the interpretation. A generic model means inference structures and types of knowledge. Analysis and categorization of knowledge will be relieved by the abstract framework. Recognition of missing and incomplete knowledge will be easier.
- It takes less effort to change and to extend the model than to establish changes and extensions for the implemented system.

Disadvantages of the model-based approaches are:

- The models, except for implemented problem solving methods, are not operational so that the dynamic running of the model can not be checked directly.
- The advantages of the rapid prototyping approaches lapse.

In the model-based approaches two main directions exist: approaches which allow general new development or adaptation of non-operational models and approaches with predefined, specialized and implemented problem solving methods. Examples for approaches of the first main direction are KADS (Breuker, Wielinga, 1989) and the cognitive task analysis (Roth, Woods, 1989). An example of an approach with predefined, specialized and implemented problem solving methods is the approach of models based on strong problem solving methods (Puppe, 1993). The approaches of the first main direction have the disadvantage that the models are not operational. Therefore, only the implemented model at the end of the modelling phases is able to run. For this reason it is possible that failures in the design are recognized only in the implemented system. However, in the approaches of the second main direction, operational models are received very quickly so that a combination of rapid prototyping and modelling is possible.

## An Integrated Method for Model-Based Knowledge Acquisition

To lessen the disadvantages of the rapid prototyping and the model-based approaches for developing knowledge-based systems, a new model-based method was developed (Borndorff-Eccarius, 1998). It integrates three methods: the model-based method of cognitive task analysis (Roth, Woods, 1989; Borndorff-Eccarius, Johannsen, 1993), the method of models based on strong problem solving methods (Puppe, 1993), and rapid prototyping. The problem solving method mentions how the domain knowledge is used for solving the problem. The stronger a problem solving method is, the more the representation and the function of the domain knowledge is prescribed.

First, the knowledge engineer performs cognitive task analysis (see Figure 1). In the initial phase, the knowledge engineer builds the competence model. The competence model describes the requirements for competent performance in the domain. In the next phase, the knowledge engineer investigates how experts and less experienced practitioners perform their tasks. In this phase, the performance model is developed. It describes knowledge and strategies that characterize good and poor performance in the actual environment. Based on these two models, the most appropriate problem solving model is selected. The problem solving model consists of the problem solving method and the types of knowledge. The domain model is built based on the problem solving model. Knowledge contained in the performance model flows into the domain model which is completed with additional knowledge.

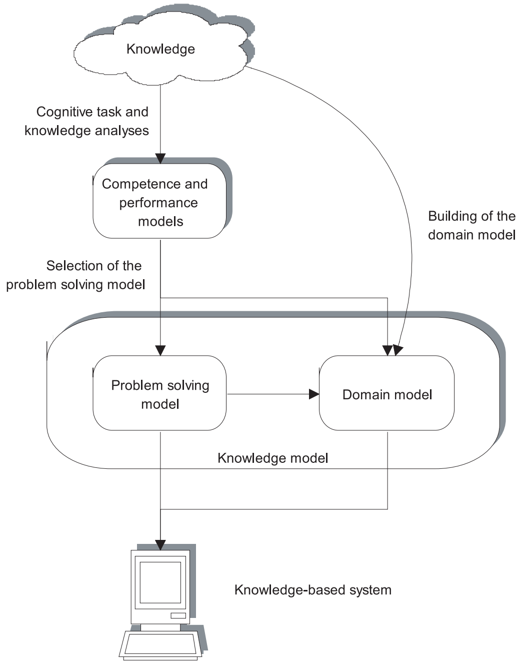



*Figure 1: Integrated Method for model-based knowledge acquisition*

The problem solving model and the domain model, with application domain specific knowledge, form the knowledge model. Using an appropriate tool, the problem solving model can be operationalized. Whereas the cognitive task analysis, knowledge analysis, and the selection of the problem solving model are performed by the knowledge engineer, the domain model can be built to a large extent independently by the expert using an appropriate computer-aided knowledge acquisition tool.

## Knowledge Acquisition Tool TEMPO

The interactive knowledge acquisition tool TEMPO with a graphical user interface supports the expert in building and adapting the domain model to the problem solving model of state-based diagnosis. TEMPO uses representations of knowledge in terms on the abstraction level of the expert. This enables the expert to build, to expand, and to adapt the domain model to a large extent independently by himself. For this purpose, plant data and data from the process database can be used. Examples of cases of failure support the expert in reproduction of his or her problem solving behaviour. The generalization of these cases is supported by TEMPO with a learning method. TEMPO considers the temporal aspects of the symptoms and information necessary for diagnosis.

The knowledge model becomes operationalized by the state generator, the rule generator and the rule compiler of TEMPO. Hence, for the rapid prototyping an executable prototype can be generated with TEMPO and the process-independent version of CAUSES. CAUSES is a knowledge based system using the strong problem solving method called "state-based diagnosis." For the validation of the knowledge bases, the expert can examine the prototype experimentally. Subsequently, he or she can revise the domain model using TEMPO.

### Problem Solving Method State-Based Diagnosis

In the domain of dynamic technical systems, a problem solving method is needed which considers multiple faults and the changeability of symptoms and information necessary for diagnosis over time. Such a strong problem solving method is the state-based diagnosis (Borndorff-Eccarius, 1990; Borndorff-Eccarius, 1992). The state-based diagnosis was developed based on cognitive task and knowledge analyses (Borndorff-Eccarius, 1993).

The state-based diagnosis consists of three steps:

1. Determining system states based on particular state transition indicators.
2. Generating hypotheses and determining the rule classes for step three.
3. Testing the hypotheses using the determined rule classes.

The state-based diagnosis uses 14 different rule types which can be divided into 4 groups: rules determining and generating states, rules for generating hypotheses and determining rule classes for step three, rules for testing the hypotheses, and auxiliary rules.

### Types of Knowledge for the State-Based Diagnosis

The strong problem solving method called state-based diagnosis prescribes different types of knowledge:

- structure of the plant and the automation system,
- functional relationships between states of components and process variables as well as the behaviour of the process in normal and in failure situations,
- states and state transitions,
- causes and their diagnosis.

The different types of knowledge can be acquired from different sources of knowledge like piping and instrumentation diagrams, data bases containing results of the planning phase of the plant, process data bases, handbooks, simulations, and experts. For more details see (Borndorff-Eccarius, 1993; Borndorff-Eccarius, 1998).

### Domain Model

Each type of knowledge is represented by a different intermediate representation. In computer-aided knowledge acquisition, the intermediate representations consist of the models which are parts of the domain model (see Figure 2) and of the graphical representations of the models. The graphical representations serve to the communicate with experts.

The structure model can be represented graphically by a plant diagram, functional relationships and behaviour of the process in time–lines, states and state transitions in state transition diagrams, causes and their diagnosis in causes diagrams. Time–lines are tables in which different types of information are represented against time flow. The state model and the diagnosis model are described by directed graphs. For building the models of a domain model different editors are provided.

To aid the expert, the plant diagram can be built by the knowledge engineer or a programmer. But for the other three types of knowledge, the expert is necessary. To help the expert to reproduce his or her problem solving behaviour, data from failure situations are provided. The expert selects typical and atypical examples of failure situations. The information which the expert needs for the diagnosis are represented in the time–line. Adding states, causes and their diagnosis, the time–line is then completed by the expert. The time–lines worked on in this way form the case base.

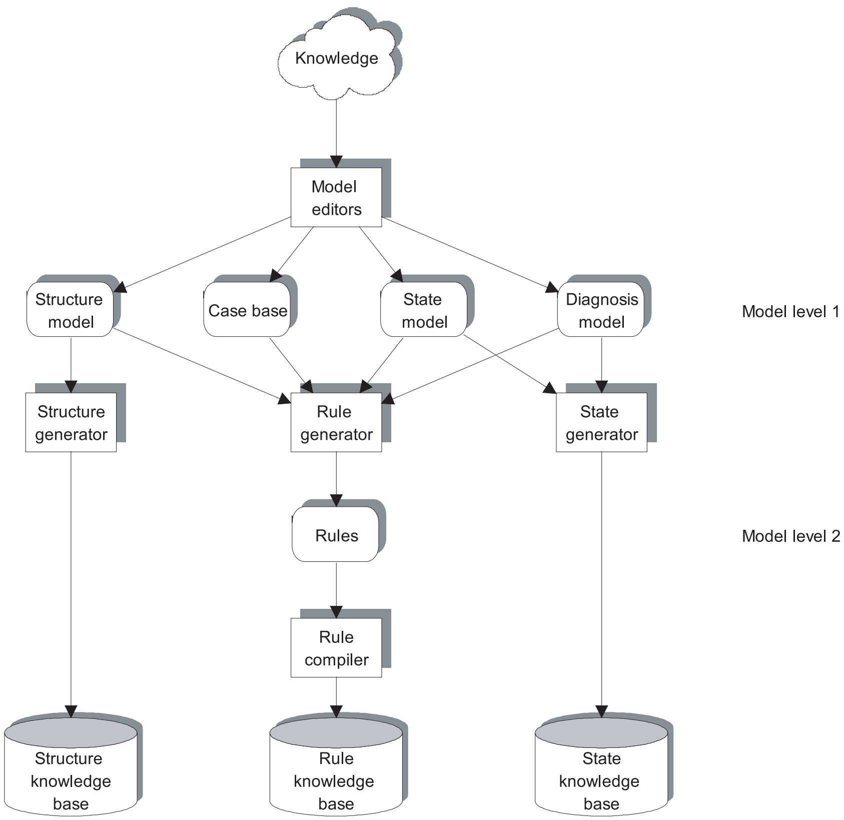



*Figure 2:Intermediate representation and rule generation*

From these four intermediate representations of the knowledge, the knowledge bases are generated by the structure generator, the state generator, and the rule generator (see Figure 2).

## Generalization of Cases and Rule Generation

The rule generator uses the structure model, the case base, state model and the causes for generating the rules. This is done in the following steps:

1. Initializing of the causes graph with cases.
2. Generalization of cases.
3. Generating rule classes.
4. Generating rules.

Before generating rules, the rule generator assigns the cases to the causes diagram (see Figure 3) and generalizes the cases. The cases described in the time–lines are related to causes nodes in the causes diagram via the causes given in the corresponding column. In this context, a case description consists of symptom relationships, checks, a test procedure, or any combination of them necessary for the diagnosis of a cause in a state.

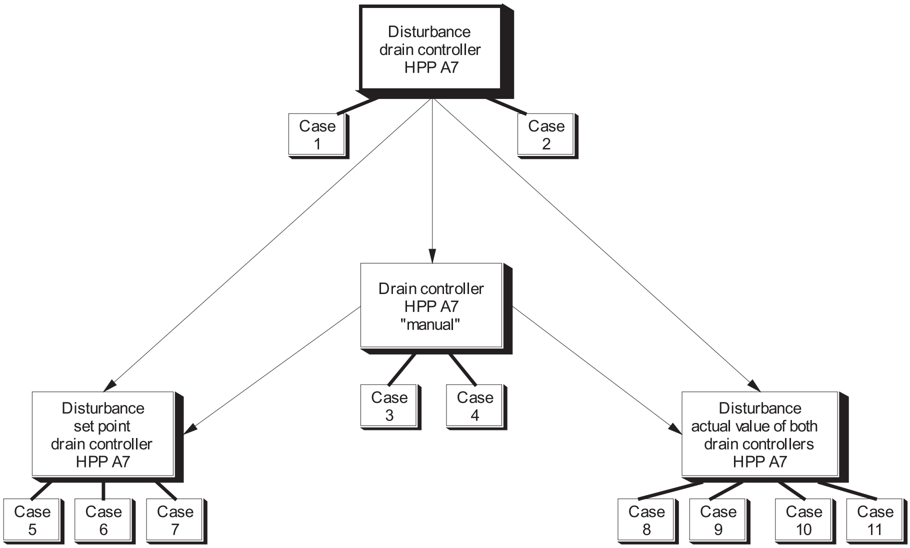



*Figure 3: Example of a causes diagram*

During the generalization, the succeeding nodes of each node with several successors are investigated. If for each successor at least one case exists with the same symptom relationships, the same checks, or the same test, then these are removed from the cases and assigned to the corresponding generalized case of the node under consideration. Starting from the sinks of the graph, this is continued until the sources of the graph are achieved. An advantage of this generalization is that the expert needs not to create cases for each node in the causes diagram.

This algorithm can be considered as a simple machine learning method of the type "learning from examples" (Michalski, 1986; Michalski, 1987). The learning effect of the generalization is that the description of the diagnosis of a causes node is independently extracted from the descriptions of the diagnosis of its successor nodes. In this way, new descriptions of the example set are created. The advantage of this learning method is that generalized cases and also generated rules remain comprehensible for experts. This is a difference from the other methods of the type "learning from examples."

After the generalization of cases, the rule generator creates rule classes for the different types of rules and for the different functional domains of the plant. Using particular frames and their slots from the models, rules are generated. For the intermediated representation of the rules (see Figure 2), the formal language TEMPO–RL was developed. It enables a representation in a form comprehensible for the expert and independent from a particular implementation language or development environment. In addition, TEMPO–RL permits descriptions of the changeability of information over time and relations between the information in regard to time.

The compilation of each rule into the implementation language of the knowledge–based system is done directly after its creation. Each time when the slot value of the frame representing the rule is overwritten, the compiler is activated by a demon. The advantage is that only the newly created rules are compiled.

The rules are taken over into the knowledge–based system, after they are checked by the expert. For this purpose, the expert uses the rule editor. If he or she does not agree with some rules, he or she can change the models and recall the rule generator. In this way, the knowledge bases are generated in several iterations.

## Evaluations

TEMPO was developed using the method of rapid prototyping. At different points in time, two subjective evaluations were executed. A first evaluation was done before the implementation of the tool. A walk–through using the draft of the user interface on paper was done with an expert. Variants of menus were proposed and discussed. The results were considered in the revision of the tool before implementing it.

A second subjective evaluation with an expert was performed after the prototype was implemented. The goal of the evaluation was to get assessments of the effectiveness (Rouse, 1991) and the usability with the aspects comprehensibility, learnability, and satisfaction (Nielsen, 1993). The result of the evaluation was altogether positive with some proposals for improvement and extensions. For more details see Borndorff–Eccarius (1998).

## Conclusions

With the modular construction of TEMPO, it can be extended for other strong problem solving methods, for example for model-based diagnosis or case-based diagnosis. Therefore, additional editors for other intermediate representations can be implemented. For additional rule types, the rule generator, TEMPO-RL, and the rule compiler can be extended. Another possibility for an extension of TEMPO is an additional editor for hierarchical task analysis representations (Kirwan, Ainthworth, 1992). In this case, TEMPO can already be used in the first phase of the cognitive task analysis. During further development of the prototype of TEMPO, additional evaluations and usability tests with a larger number of users are necessary.

## References


Borndorff-Eccarius, S. (1990). CAUSES – State-Based Diagnosis Support Expert System. ESPRIT – GRADIENT P857, Rep. No. IMAT-MMS-11. Kassel: Labor für Mensch-Maschine-Systeme (IMAT-MMS), GhK-Universität

Borndorff-Eccarius, S. (1992). CAUSES: State-Based Diagnosis for Supporting Control Room Operators. Proceedings 11th European Annual Conference on Human Decision Making and Manual Control, Valenciennes (France), November 17–19, 1992. Valenciennes: LAIH, University of Valenciennes

Borndorff-Eccarius, S. (1993). Supporting Knowledge Acquisition for Knowledge-Based Fault Diagnosis Systems. Proceedings 12th European Annual Conference on Human Decision Making and Manual Control, Kassel (Germany), June 22–24, 1993. Kassel: University of Kassel

Borndorff-Eccarius, S., Johannsen, G. (1993). Supporting Diagnostic Functions in Human Supervisory Control. Conference Proceedings 1993, IEEE International Conference on Systems, Man and Cybernetics, System Engineering in the Services of the Human, Le Touquet (France), October 17–20, 1993

Borndorff-Eccarius, S. (1998). Rechnergestützte Wissensakquisition für wissensbasierte Diagnosesysteme im Bereich dynamischer technischer Systeme. Dissertationen zur künstlichen Intelligenz; Bd. 176. Sankt Augustin: Infix

Breuker, J., Wielinga, B. (1989). Models of expertise in knowledge acquisition. In G. Guida, C. Tasso (Eds.), Topics in Expert System Design. Amsterdam: North-Holland, pp. 265–295

Buchanan, B. G., Barstow, D., Bechtal, R., Bennet, J., Clancey, W., Kulikowski, C., Mitchell, T., Waterman, D. A. (1983). Constructing an expert system. In: F. Hayes-Roth, D. A. Waterman, D. B. Lenat (Eds.), Building Expert Systems. Reading, M. A.: Addison-Wesley, pp. 127–167

Freiling, M. (1985). Starting a Knowledge Engineering Project: A Step-by-Step Approach. AI Magazine, Fall 1985

Grover, M. (1983). A Pragmatic Knowledge Acquisition Methodology. Proceedings of the 8th International Joint Conference on Artificial Intelligence, Karlsruhe, August 8–12, 1983

Harmon, P., King, D. (1989). Expertensysteme in der Praxis. 3. Aufl. München: Oldenburg

Kirwan, B., Ainsworth, L. K. (Eds.). (1992). A Guide to Task Analysis. London: Taylor & Francis

Michalski, R. S. (1986). Understanding the nature of Learning: Issues and Research Directions. In R. S. Michalski, J. G. Carbonell, T. M. Mitchell (Eds.), Machine Learning: An Artificial Intelligence Approach. Vol. II. Los Altos, CA: Morgan Kaufmann, pp. 3–25

Michalski, R. S. (1987). Learning Strategies and Automated Knowledge Acquisition. In: L. Bolc (Ed.). Computational Models of Learning. Berlin: Springer, pp. 1–19

Nielsen, J. (1993). Usability Engineering. San Diego: Academic Press

Puppe, F. (1993). Systematic Introduction to Expert Systems. Knowledge Representations and Problem-Solving Methods. Berlin: Springer

Rouse, W. B. (1991). Design for Success: A Human-Centred Approach to Successful Products and Systems. New York: Wiley

Roth, E. M., Woods, D. D. (1989). Cognitive Task Analysis: An Approach to Knowledge Acquisition for Intelligent System Design. In: G. Guida, C. Tasso (Eds.), Topics in Expert System Design. Amsterdam: North-Holland, pp. 233–264

# Electronic Handbooks Supporting Fault Diagnosis Tasks

*Martin Hollender*

## Abstract

The combination of an automatic fault diagnosis module and an electronic troubleshooting manual results in a support system which allows a close interrelation of human and machine fault diagnosis performance. The electronic manual acts as a cognitive interface and puts the suggestions of the automatic fault diagnosis module into the context of related knowledge so that they can be easily verified by the human diagnostician.

## Introduction

Modern technical systems are highly complex, and product life cycles are extremely short. Therefore, it is impossible for operators to know all the necessary information for troubleshooting by heart. Instead, they have to consult external knowledge sources which are often delivered on electronic media (Boy, 1992).

This chapter presents an approach on how to combine a diagnostic expert system with a troubleshooting handbook. The diagnostic expert system tackles the symptom related side of fault diagnosis whereas the structures of the electronic book support the topographic reasoning of the human troubleshooter.

## Human Fault Diagnosis

Methods based on mathematical principles are no more than a precondition for a successful fault diagnosis support system. To be really helpful for its users, the support system has to be related to the ways humans actually do fault diagnosing.

Rasmussen (1981) distinguishes between symptomatic and topographic search. The first is pattern and cue oriented, whereas the latter is a more systematic screening of the system. Empirical studies in the medical (Elstein et al., 1975) and technical domain (Bereiter and Miller, 1989) emphasize the central role of hypotheses in human fault diagnosis. First the hypotheses are generated and then they are verified. This approach is called “Hypothesis & Test”. The cognitive explanation (Elstein et al. 1975, Wickens 1984, Reason 1990) is that hypotheses act as central memory organizers of the problem solving process. Hypotheses transform an indefinite problem (Which failure is it?) into a definite one (Is it failure A, B or C?). Because of the limited size of human working memory, more than 5 hypotheses are rarely considered in parallel. The network of hypotheses guides the gathering of new information. If new evidence contradicts the current network, the network should be modified accordingly.

Martin Hollender joined Gunnar's group in 1990 and worked on electronic hand-books and co-operative design. He left after completing his PhD in 1994 works now as an independent Software Consul-tant in Heidelberg, Germany.

This way of diagnosing faults is normally very pow-erful, but also imposes some well-known problems:

- *Confirmation bias or cognitive tunnel vision* (Wickens, 1984). Diagnosticians seek (and therefore find) mainly information which fits into the current network of evidence. Contra-dictory evidence is often overlooked or wrongly interpreted as supporting. This bias can be explained with the high amount of cognitive efforts necessary to change the current network of hypotheses. Especially in complex abnormal situations with high workload operators tend to act according to this bias (Rasmussen, 1981).
- *Anchoring* (Kahneman et al., 1982). The first problem solving steps inadequately influence the whole further problem solving process.
- *Overconfidence*. Human diagnosticians are often too certain that their current set of hypotheses covers the actual fault.
- *Availability / Recency*. The ease of recall from long term memory is taken as a measure for the probability of an event.

According to Rouse (1984), it is very difficult to humans to utilize information about what has not failed. Another problem is that diagnosticians often do not have enough knowledge about the technical system and about how to diagnose it. This knowledge gap cannot be closed with a simple Information Retrieval (IR) mechanism because the diagnos-ticians normally are not able to exactly specify their current information needs. The biases listed above show how important it is also to **remind** the diagnosticians of information for which they were not looking originally.

## The Cognitive Interface of “Book Technology”

Today, external knowledge for complex troubleshooting tasks is still acquired in most cases from classical documentation – be it in paper or electronic form. What is the reason for this fact? Humans have developed powerful skills and methods for communicating knowledge with the help of “book technology”. The mere ability to read words and sentences is only the most basic mechanism. For communicating complex facts, many more mechanisms like paragraphing, layout and table of contents support the authors in expressing their ideas. The essence is that “book technology” offers an attractive interface for presenting knowledge highly compatible to human cognition. Modern hypertext systems (e.g. based on Web, HTMLHelp or PDF technology) add powerfull search capabilities, but all try to emulate the classical paper book. In fact, it is a major current research goal to bring electronic book technology closer to its paper model (Gates, 2001).

## Situated Learning

Troubleshooters consult a support system because they need some additional knowledge to perform a specific diagnostic task. This situation is a fruitful basis for learning (Lave and Wenger, 1991; Brown and Duguid, 2000). The troubleshooters are highly motivated because they want to perform their task, and the successful repair of the technical system is a powerful intrinsic reward and a kind of self-evaluation. Of course, learning requires extra efforts and time, which is not available in some situations. But if the employing company is interested in highly qualified troubleshooters, learning on the job is one of the most effective training methods. Well suited electronic manuals are an important means to enable this learning by doing. Therefore, future **C**omputer **B**ased **T**raining (CBT) and **D**ecision **S**upport **S**ystem (DSS) technologies will move close together and eventually even merge.

## Imperfect Fault Diagnosis Support

Automatic fault diagnosis modules for complex technical systems often are very complex themselves. In many cases, a cost-effective engineering of such fault diagnosis modules means an imperfect fault diagnosis performance. Such a module can make valuable contributions to the fault finding process in many cases, but in other cases the contribution might be less valuable or even wrong.

In the Information Retrieval (IR) field systems are evaluated with the help of *recall* (the ability to find relevant documents or solutions) and *precision* (the relevant / irrelevant ratio). Of course it is much more difficult to evaluate automatic fault diagnosis modules, but it is very important to note that in analogy to the IR field, even imperfect fault diagnosis support can be valuable (nobody expects that a keyword of a book *always* leads to an interesting page, but if it does, it is helpful). The construction of a perfect automatic fault diagnosis module might require too much effort for the value it can offer. The lacking accuracy of the automatic fault diagnosis module has to be carefully considered in the design of the overall support system.

## Implementation

The ideas presented in this chapter have been implemented and tested in a program called **E**lectronic **D**iagnosis **S**ystem, EDS (Hollender, 1995). EDS runs on standard Personal Computers and is a so-called "expertextengine" (Rada and Barlow, 1989) because it provides the basic hypertext and **C**ase-**B**ased **R**easoning (CBR) mechanisms without any reference to a technical system. The system-specific information is stored in "troubleshooting files" (in analogy to knowledge bases of expert systems). EDS files are one of the first approaches where data is stored in a SGML-based format, an approach that is now common place with the highly successful XML technology.

EDS offers three support mechanisms:

- The **F**ault **D**iagnosis-Network (FD-Network) is a hypertext troubleshooting manual with standardized presentation formats and cross-references especially suited for fault diagnosis.
- The automatic fault diagnosis module generates hypotheses. It measures the similarity between the information needs (or symptoms) currently specified and each page of the electronic book.
- The pathfinder module relates the results of the automatic fault diagnosis module to the FD-Network.

The three modules will be described in the following sections.

## Fault Diagnosis Network

One of the main goals of structuring fault diagnosis information is to offer *"predictable paths to expected information"* (Herrstrom and Massey, 1989). In technical domains the hierarchical structure of system components is an intuitive structuring method. A hierarchical structure of the information is also suggested from a human factors point of view (Herrstrom and Massey, 1989). Especially in hypertext systems, disorientation of the readers (termed "Lost in Hyperspace") has to be carefully avoided. The top level of the FD-network visualizes the component hierarchy. In addition, this hierarchy lists all possible faults locations.

In the second level, standardised tables are used to summarize the fault diagnosis knowledge of each component. In EDS, these tables provide a column each for *faults*, *causes*, *effects* and *countermeasures*.

If necessary, each item can be expanded to a third level offering detailed information.

This rigid structure can be extended by intermediate levels or non-hierarchical cross-references. For example, causally connected components can be cross-referenced with "cause" and "effect" links.

### Automatic Fault Diagnosis Module

The diagnostic module can be seen either in an Information Retrieval or Case-Based Reasoning tradition. Each page of the electronic book has an attached symptom vector. This vector describes which symptoms or keywords point to the page. Both three-point scales (no, don't know, yes) and five-point scales (never, very unlikely, don't know, very likely, always) can be used for the input of symptoms. The use of a five-point scale is very important, because some symptoms are connected closer to a page than others. Results presented in (Elstein et al., 1978) and (Peng and Reggia, 1990) indicate that a five-point scale should be enough to express the relevant fault diagnosis knowledge.

If users want help from the automatic fault diagnosis module, they first have to specify their current situation. This can be done by building a symptom vector with the same structure as the vectors describing the single pages. From an Information Retrieval point of view, this vector stands for the user's information needs and is called query-vector. Again, a five-point scale is necessary because the users may want to express their degree of certitude about the individual symptoms.

The automatic fault diagnosis module then computes the similarity between the vector describing the current situation and each page of the book. The verbal expressions (i.e., no, yes) are first transformed into numbers (0, 1). The similarity between the vectors can be easily computed with the help of the standard cosine product. After this procedure the pages of the electronic book can be ranked by similarity to the user's information needs. The pages on the top of the list are probably interesting to read. A threshold decides from which value of similarity on the pages are no longer considered possible solutions of the problem.

The approach is very similar to the vector space model (Salton and McGill, 1983) coming from the Information Retrieval field. It also fits to Case-Based Reasoning methods (Pfeifer and Richter, 1993). Although very powerful in dealing with complex and imprecise relations, the approach has to be modified to accomodate the special aspects of fault diagnosis. If for example a page (= a hypothesis) is definitely connected to a symptom which is definitely absent in the current situation, this should not only result in a lower rank, but this page has to be totally excluded from the resulting list. The modified method is strongly influenced by the set theoretic ideas of Peng and Reggia (1990).

The direct presentation of the results produced by the automatic fault diagnosis module is included in EDS as one possibility. A ranked list of all hypotheses is offered for direct access to the different pages. One issue is, however, that these often very specific and detailed solutions should be integrated into the structure of the electronic book. If only the page with the solution is presented, the relation to important other information may be unclear. In the following a method of how to avoid disorientation is presented.

### Pathfinder Module

Ideally, the solutions found by the automatic fault diagnosis module are very specific and detailed pages. That implies that the suggestions of the automatic fault diagnosis module are often not *starting* points for reading, but *finishing* points. While those pages should be read last before acting, other *more general* pages should be read before. EDS finds paths through the structure of the electronic book leading to the solutions found by the automatic fault diagnosis module. Each cross–reference of the type "Pointing–to–detail" leading directly or indirectly to suggested information is graphically emphasised, i.e., with a change of colour or a special symbol. EDS was one of the first implementations of coloured hypertext links, which means links that change their behaviour and / or appearance according to the current context.

The computed paths ensure that the solutions are presented in the context of the overall book. The given context enables the readers to verify the suggested solutions. The structure of the electronic book supports hypothesis testing. On their way towards the solution, readers might pick up some interesting information not looked up for originally (incidental learning).

### Solutions in Context

How can the combination of a fault diagnosis module and a hypertext manual present solutions in context? Context is defined as problem context, emphasizing the progression and environment of a problem solution. Not only the solution is important, but also the way towards this solution, and possible alternative solutions are considered as integral parts of the decision support. Context is needed because human operators have to understand the solution so that they can effectively test the hypothesis. Two examples shall demonstrate how context can help to introduce important related hypotheses.

### 1st Example: *Causal context*

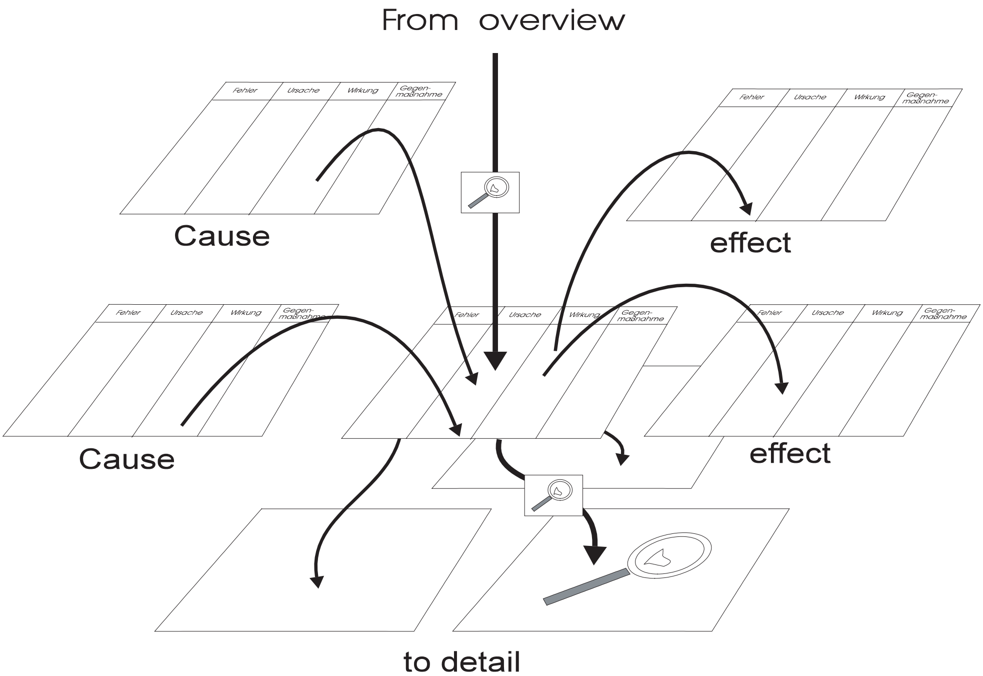
The alternator of a car is driven by the cone belt. Both components are causally connected because the alternator cannot work without the cone belt. Suppose that the symptoms at hand are indicating a specific problem with the alternator. The automatic fault diagnosis module therefore suggests a page dealing with very specific alternator problems. The pathfinder module now generates the path

1) General Overview
2) Summary alternator
3) Specific problem alternator.

The second page "Summary alternator" has the standardized column "cause" which contains a link to the cone belt. This *reminds* the diagnostician that cone belt and alternator are causally connected. Checking if the cone belt is loose or missing is easy and fast. This check is highly recommended before going into the details of the alternator. Bereiter and Miller (1989) showed an expert troubleshooter falling into a similar trap in their field study.

Figure 1 shows how the "cause" and "effect" cross-references of an intermediate page support reasoning about function and therefore may entertain alternative hypotheses.

*Figure 1: Causal context*



### 2nd Example: *Differential diagnosis context*

To verify a hypothesis one should also verify all differential diagnoses, because differential hypotheses have very similar symptoms but may require different countermeasures.

In EDS this can be solved with an intermediate page listing all differential diagnoses placed before pages with specific diagnoses.

This ensures that all paths leading to a specific diagnosis pass the page containing the differential diagnoses. If the users are not interested in differential diagnoses, they can easily follow the highlighted cross-reference pointing to the specific diagnosis, and ignore the differential diagnoses. If they are interested, the intermediate page offers access to the verification of all differential diagnoses.

## Co-operative Support of Diagnostic Tasks

It is very important that the support system does not dominate the diagnostic problem solving process. Troubleshooters can only be responsible for decisions they understand (Of course, understanding is often connected with effort). If the automatic fault diagnosis module cannot be guaranteed to be perfect, the human operator should control the problem solving process and have the last word. That is why the opportunity to verify the suggestions of the automatic fault diagnosis module is crucial. The automation of routine diagnostic tasks makes not much sense if the more difficult problems remain for the human operator (Rouse, 1984; Johannsen, 1993).

In EDS, it is up to the human operator to ignore the automatically generated hints (in this case only the electronic book is used), or to always follow the hints (which is similar to using a diagnostic expert system). Maximum co-operation is reached, if the operators verify the advices via the help of the context offered through the electronic book, and decide case by case if they should follow the suggestions or ignore them.

## Architecture

EDS consists of a book and an index layer (Frisse and Cousins, 1989).

The index layer can be quite complex containing hundreds of keywords. The conventional alphabetical structure of the index is only one very basic possible structure. A better practice is to group together task-related keywords. An example would be to combine all keywords dealing with visual inspections in one group. The index layer can be used for two purposes:

- Connect each page of the book layer with specific keywords.
- Specify the user's information needs with a query-vector.

The book layer contains the FD–Network and therefore the main information of the troubleshooting support system. As in the paper world, a book without index can be valuable, but an index without book makes no sense.

Both layers are designed with the structure and content editor. This editor allows to specify the links and nodes that make up a troubleshooting file. The nodes can contain pictures, sounds or text. Very often standardized tables are used for the presentation of information. The links can be linear (like the pages of a book), hierarchical (like the hierarchical structure of the technical system) or web–like, which is necessary for example to model cause–effect links.

The basic architectural elements for the book and index layer are two complex object types. "Formsheets" store all the data necessary for building up pages. In addition, they store the connected index–vector. Each "Formsheet" can contain several "TextItems" which contain a short text and links to other "Formsheets". Additionally, each "TextItem" has a "type label" which can be transformed into complex behaviour. The type label "pointing–to–detail" for example is used by the pathfinder–algorithm and, if appropriate, translated into a graphical hint. Both "TextItem–" and "Formsheet–" objects are manipulated with the structure and content editor. The persistent storage for the objects are the "troubleshooting–files".

## Applications

The electronic manual approach was used for building a fault diagnosis support system for the photovoltaic inverters of SMA, an electronics company located in Kassel. These systems are installed decentrally and feed photovoltaic energy into the public net. The troubleshooting file is used to document the fault diagnosis know–how. The support system is currently being tested inside the company. In the future, a troubleshooting file might accompany each device as a decentral troubleshooting aid.

Another support system was built for two different motor management units used in the Volkswagen Golf III. The modern motor management units impose a new level of complexity requiring both a better fault diagnosis training for the mechanics and better fault diagnosis tools. The approach presented in this chapter offers an integrated solution for both problems. This support system is only a prototype for demonstration and test purposes because it covers only a small subset of the faults occurring in the daily work of a motor garage.

## Evaluation

First experiments with more than 50 subjects were carried out inside the laboratory with typical fault diagnosis scenarios. As stated in Wickens (1984) it was observed that the use of the support system first requires additional skills and efforts. That means that a good introduction of and basic training for the support system is very important for its acceptance. Because user-friendliness has been a major design goal, the subjects needed only half an hour to learn how to use the support system. Subjects aided by the automatic fault diagnosis module found the faults significantly faster and in a more focused way than those using only a simple electronic book.

## Conclusion

EDS demonstrates the use of an electronic manual as a cognitive interface for a fault diagnosis support system. The pathfinder algorithm puts the suggestions of the automatic fault diagnosis module into the context of an electronic manual. The suggestions are not presented in isolation, but can be verified step by step, from overview to detail. This approach emphasizes the responsibility and skills of the human operator. In fact, EDS can be viewed as a "Tutor on the job". Because electronic manuals are rapidly spreading into the aviation, automotive and computer industry, the presented "smart manual" approach will be of great further interest.

## References

Bereiter, S. R., and S. M. Miller, (1989) A field based study of troubleshooting in computer-controlled manufacturing systems. IEEE Trans. Systems, Man, Cybernetics, Vol. 19, No. 2, pp. 205–219

Boy, G. A. (1992) User-centered indexing of hypertext documents. Preprints $5^{th}$ IFAC Symposium on Analysis, Design, and Evaluation of Man-Machine Systems, The Hague, Netherlands

Brown, J. S. and P. Duguid, (2000) The Social Life of Information. Harvard Business School, Boston, MA

Elstein, A. E., L. S. Shulman, and S. A. Sprafka, (1978) Medical Problem Solving. Havard University Press, Cambridge, MA

Frisse, M. and S. B. Cousins (1989) Information retrieval from hypertext: update on the dynamic medical handbook project. Hypertext '89, Pittsburgh, pp. 199–212

Gates, B. (2001) Keynote speech CHI. Seattle, WA, April 2, 2001

Herrstrom, D. S., and D. G. Massey (1989) Hypertext in context. In: The Society of Text. (E. Barrett, Ed.), pp. 45–58, MIT Press, Cambridge, MA

Hollender, M. (1995) Elektronische Handbücher zur Unterstützung der wissensbasierten Fehlerdiagnose. VDI–Verlag, Düsseldorf

Johannsen, G. (1993) Mensch–Maschine–Systeme. Springer, Berlin

Lave, J. and E. Wenger (1991) Situated Learning: Legitimate Peripheral Participation. Cambridge University Press, Cambridge, MA

Kahneman, D., P. Slovic, and A. Tversky (1982) Judgment under Uncertainty: Heuristics and Biases. Cambridge University Press, Cambridge, MA

Peng, Y. and J. A. Reggia (1990) Abductive Inference Models for Diagnostic Problem–Solving. Springer, New York

Pfeifer, T. and M. M. Richter (1993) Diagnose von technischen Systemen. DUV, Wiesbaden

Rada, R. and J. Barlow (1989) Expert systems and hypertext. Knowledge Engineering Review, 3, pp. 284–301

Rasmussen, J. (1981) Models of mental strategies in process plant diagnosis. In: Human Detection and Diagnosis of System Failures. (J. Rasmussen and W. B. Rouse, Eds.) pp. 241–258. Plenum Press, New York

Rouse, W. B. and R. M. Hunt (1984) Human problem solving in fault diagnosing tasks. In: Advances in Man–Machine Systems Research. Vol. 1 (W. B. Rouse, Ed.) pp. 195–222, JAI Press, Greenwich, UK

Reason, J. (1990) Human Error. Cambridge University Press, Cambridge, MA

Salton, G. and M. McGill (1983) Introduction to Modern Information Retrieval. McGraw–Hill, New York

Wickens, C. (1984) Engineering Psychology and Human Performance. C. E. Merrill, Columbus, OH

# Approximative Process Visualization based on Qualitative Knowledge and Fuzzy Logic

*Salaheddin Ali*

Sallah Ali, after receiving his Diploma from the University of Stuttgart, joined Gunnar Johannsen's research group and worked on participative design. He finished receiving his PhD in 1998 and works now as a professor at a Palestinian university.


## Abstract

A novel design technique for the construction of human–machine interfaces is presented. This technique strives after increased user orientation adapting human–machine interfaces to the cognitive structures of human users. Different models of the human knowledge that are available in analogous or conceptual form have to be considered, both in the design of a graphical user display and in the design of the underlying information management system. Fuzzy logic is used for translating natural language procedures acquired from operators into objects in knowledge bases. Thus, technical systems can be considered and controlled from different viewpoints.


Keywords: process control; human–machine interface; knowledge–based systems; object–oriented software design, fuzzy logic.

## Introduction

In the following, an integrated approach with new design methods for human–machine interfaces in process control will be presented. All methods and techniques developed during this research work supported partly by the German Research Foundation (DFG) were evaluated and tested with a simulation of a chemical distillation process. This simulation was developed at the Institute of System Dynamics and Control Engineering of the University Stuttgart. It represents a typical, highly complex system and is thus very suitable for demonstrating the methodology.

Technical systems are mostly visualised by conventional user displays based on topological representations and flow diagrams (VDI/VDE 3695, 1986). For large and complex installations, views in these kinds of user displays are split up according to system / sub–system hierarchies. Such views become intricate if complex plants have to be visualised. The design method and technology of this study is based on different models of human operators and the technical process. These models are acquired from experienced operators through task and process analysis must be used in integrated way to achieve a powerful work environment for human operators.

Presentations of the different models containing analogous and conceptual knowledge are considered, both in the graphical design of the user display as well as in the construction of software structures realised in the from of object–oriented modules (Johannsen, 1993). With this type of visualisation, adapted to the cognitive structures of human operators, process control and supervision can be supported on different cognitive behaviour levels (see Rasmussen, 1986; 1987). A high transparency is accomplished and thus, it is possible to visualise malfunctions and process violations in an intuitive manner.

## Models of knowledge presentation as fundamental design materials

In the human–machine interface, different models of the technical process and of the operators, describing their supervisory– and control behaviour, are used to represent the process on different levels of abstraction and from different viewpoints. The different models are applied to both the design of the graphical user display and the development of the information management system of the human–machine interface. Both sub–systems are adjusted to the cognitive structures of human operators. Experiences with human–machine interfaces have shown that the visualisation of process states through the graphical user display can be a substantial aid to operators (Ali, 1997). It is essential that the human operator can observe the state of a technical process without wasting a lot of time in observation and identification of process variables. The knowledge that is required for this development is acquired through task– and process analyses and contains the following models:

- A model of the human information processes involving human decision making, adopted from (Rasmussen, 1988). This model is not explicitly used in the design of the user interfaces, but it is applied in the design philosophy.
- A state–task model containing a hierarchical order of elements obtained by task and process analysis (see Figure 1). A technical system is first divided into *critical subsystems*. Relevant process states are determined for these subsystems. The state–task model defines the mapping between these process states, and the tasks that have to be carried out by the operator. A similar description is represented in Matern (1984). The manner in which such model can aid a human operator in his task is discussed at the hand of the information– and decision––*ladder* model by Rasmussen (1988), which describes human cognitive processes as a sequence of information processing stages A human–machine interface using the state–task models should relieve and support the operators by their activities of information processing, such as *observe information and data*,

*identify present state of the system* and, last but not least, *define task; select change of system condition*. The human–machine interface mediates to the operators not only the final result of the knowledge states system state and task computed by the information processing system but also the necessity for doing tasks. As shown in Figure 1, the state–side includes elements about the state of the technical systems. On the task–side, levels containing elements about tasks, activities and actions are modelled. These task elements are categorised in task classes such as process goals, strategies and security classes.

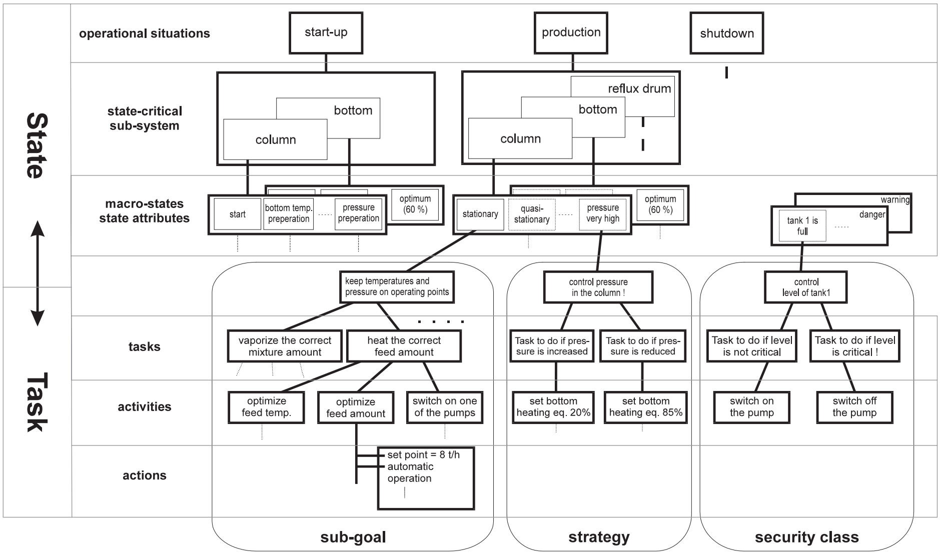



*Figure 1: State–task model of the distillation column*

- A qualitative causal model of the technical system (Funke, 1992). This model consists of the important process variables that are sufficient to describe qualitative process behaviour (the qualitative part of the model) and the causal relations between these variables (the causal part). It will be shown that causal models are partly used in the graphical design and as a basis to define the different knowledge elements in the fuzzy knowledge base.

## Approximate Knowledge-based Process Visualisation with Fuzzy Logic

The different models mentioned above are used to design knowledge objects located and managed by the information processing system as well as the corresponding graphical modules that will be presented on the user display. These models contain both descriptive or declarative knowledge, and operational or procedural knowledge. This knowledge is mostly available in the form of natural language. For the construction of qualitative models, this knowledge must be recorded and converted into a computer representation. Fuzzy logic is especially suited for this second step (Zimmermann, 1991).

Followings describe the reasons why fuzzy logic is suitable for converting and processing the knowledge used in approximate knowledge-based human-machine interfaces. For more detail information see (Ali, 1998):

- The knowledge acquired from human operators is available in a colloquial form. The application of a means, i.e. fuzzy logic, for the direct conversion of this knowledge into a computer representation leads on the one hand to shorten the development time. On the other hand it will be possible to create new kinds of display elements which correspond to the ways of human thinking (Ali, 1998).
- On higher levels of process control and supervision, users think not only in specific values, but also in linguistic terms (Kahlert, 1995).
- Undisputedly, display elements with symbolic information contents represent a central constituent of advanced user displays (Johannsen, Ali, Heuer, 1995; Johannsen, Ali, Van Paassen, 1997). To mention graphic items for the representation of states, alarms, fulfilment-grades of process goals and strengths of the urgency for doing tasks and actions (Ali, 1997).
- A further important problem with the use of graphical elements for the visualisation of process states or fulfilment-grades is the characterisation of value ranges of process variables used to describe these process information. Display elements, which are based on such values, strongly depend on the way of interpretation of the appropriate intervals.

The fuzzy rules used within the objects of the knowledge base take linguistic variables as their input. To prepare these input variables, values from the controlled process are converted into fuzzy sets. The values of the output variables of the knowledge base are ulfilment-grade values for process goals as well as strength values for states, necessity for determining which tasks are relevant.

Different inference mechanisms for calculating approximate values about the whole human–machine system are realised within the information management system. In the following, one of these mechanisms will be discussed. This method converts the fuzzy result set as it is calculated by the inference machine into a concrete value. Such values are then used to animate graphical objects on the user display, in this example for the visualisation of fulfilment – grades of process goals. Figure 2 illustrates the principle of the inference mechanism at the hand of the example *process goal of the feed*.

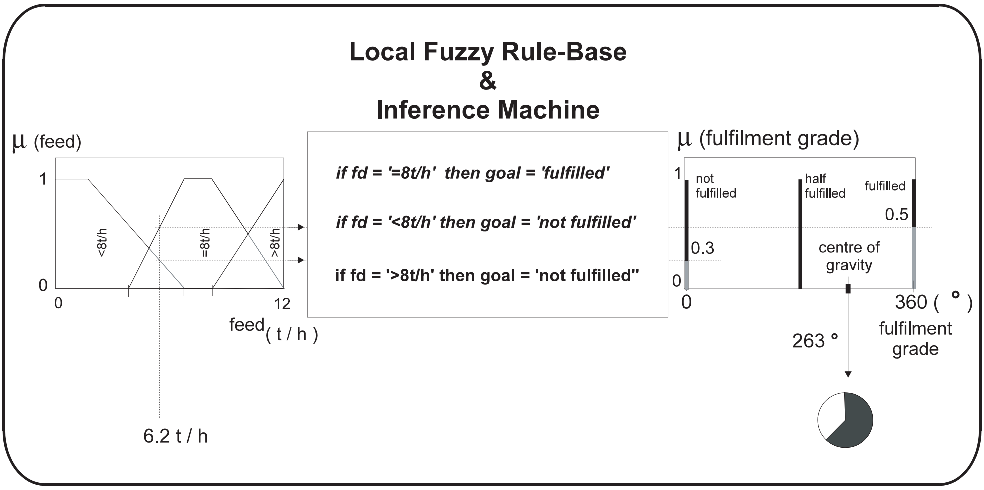



*Figure 2: Inference process for output variables of fuzzy knowledge–base for visualisation of a fulfilment–grade.*

For the defuzzification of fuzzy result sets, the centre–of–gravity method is used. This results in concrete values called fulfilment – grades. The fulfilment–grades of the goals on the user display are approximate. This means that a goal can get values with different strengths, e.g. *60 % fulfilled*. The goal value is represented on the display by a small pie–chart, displayed in the (circular) goal icon.

## Approximate knowledge–based process visualisation

During this research work, a complete human–machine interface containing both a software management system and a graphical user display has been developed. This tool allows, technical systems to be considered and controlled through different representations such as topology, causal coherence, process goals, states, necessity for doing tasks and security classes. In this section, some visualisation aspects of the approximate knowledge–based user display, the *PRISMA* user display, will be presented. Figure 3 shows the *PRISMA* user display during the visualisation of approximate states and goal fulfilment–grades of the chemical process *distillation column*. In the upper portion of the screen, various information about the process such, as operational situations and security classes, as well as states and process goals of the critical subsystems of the technical system are presented, by means of an overview. This overview window cannot be covered by other displays and, thus, the operators are always informed about the current process state. The goal icons visualised by pie–chart symbols mediate whether the goals of the influence–function units in the different critical subsystems are fulfilled or not. As illustrated above, the calculation of every pie–chart value is based on fuzzy rules and is executed by a local fuzzy inference machine.

Details of a critical subsystem can be enlarged to get more information about the macro–states (sub–states) and necessities for doing tasks. Moreover, detailed information about the fulfilment–grades of component functionalities within a function unit can also be visualised. These icons can be used to activate the corresponding topological views of the process. The operator can select any given macro state represented by a gauge icon to gather information about the rules underlying this specific macro–state. These rules are presented in the window shown on the lower right side of Figure 3.

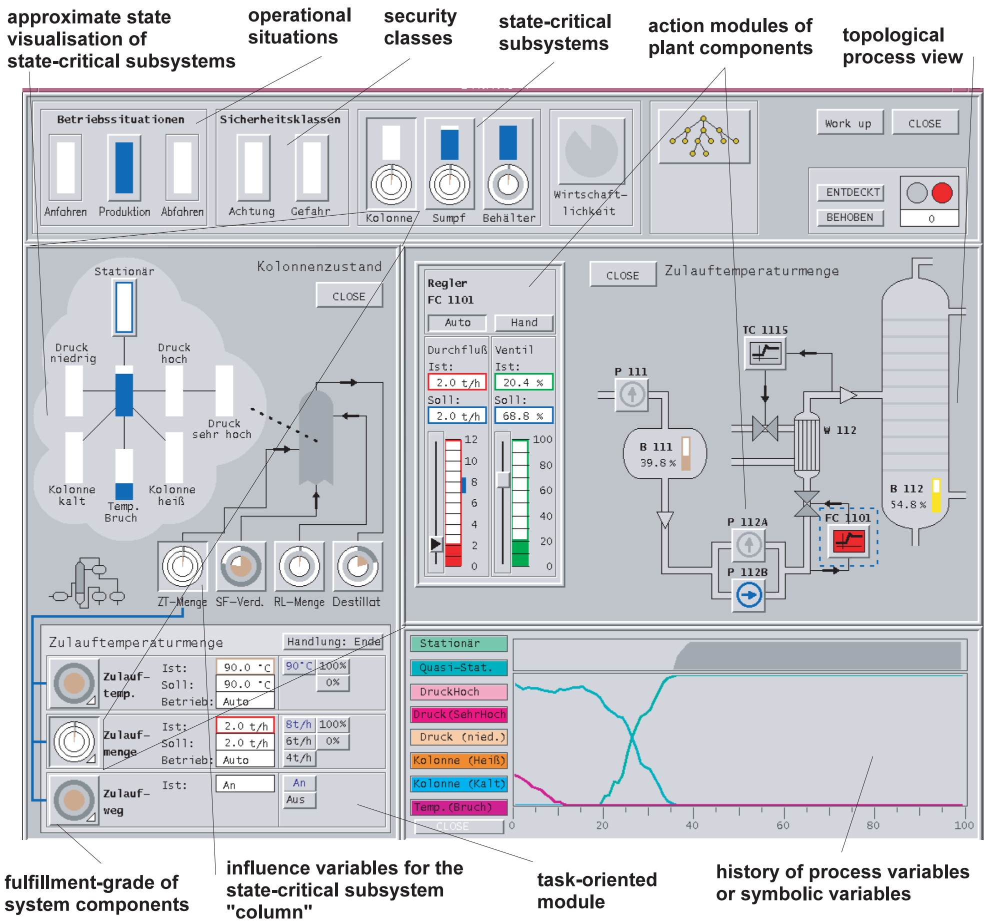
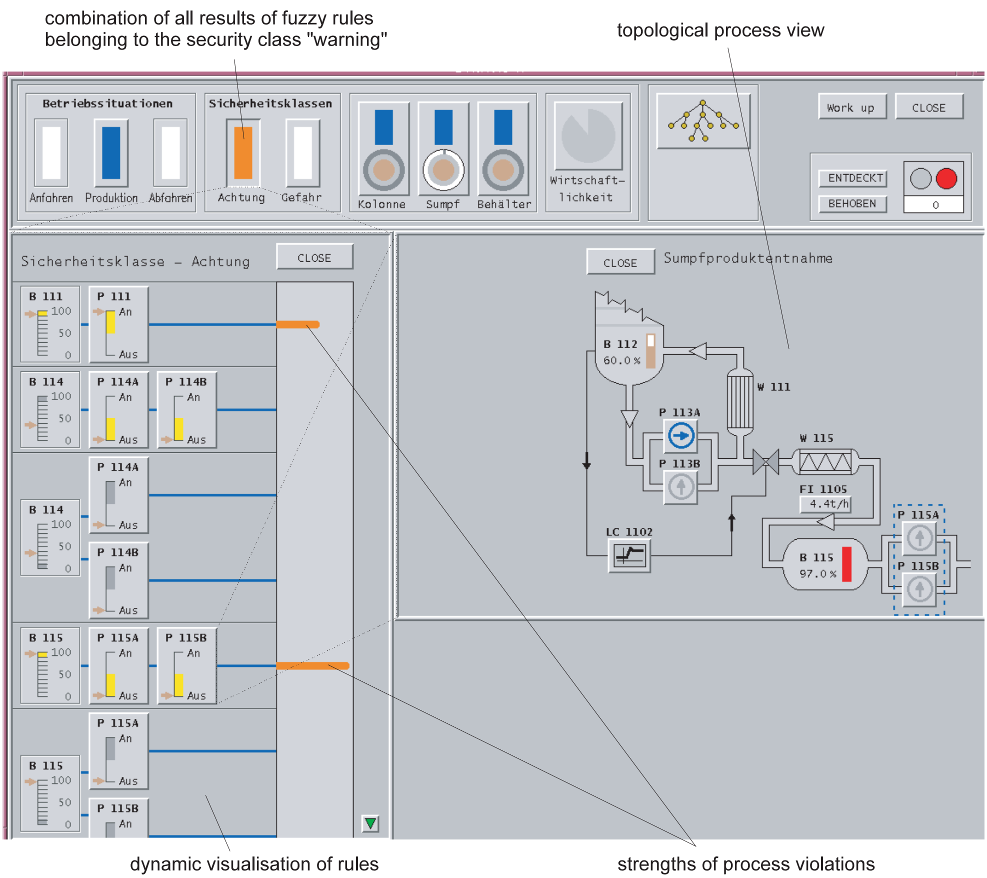



*Figure 3: The knowledge-based user display* PRISMA
*during visualisation of approximate states and goal fulfilment-grades*
*of the chemical process* distillation column

Another possible representation form supported by the *PRISMA* user display is the task-dependent state visualisation managed by a rule-based module called *security classes*. Within this object-oriented module, process violations describing illegal or undesirable combinations of process values are modelled. These combinations of process values are not related to one specific state. This means that these process violations can occurred during all operational situations. Figure 4 represents the task-dependent state visualisation supported by the *PRISMA* user interface by means of the example *security class: warning*. As shown in Figure 4, two process violations with different strengths are visualised by a graphical rule-based process view located on the left-middle side of the desktop. Approximate values for terms of security classes represented in the overview of the technical process are calculated by means of the MAX operator (Zimmermann, 1991). The MAX operator combines all results of fuzzy rules belonging to a class to a single value.

*Figure 4: The knowledge-based user display* PRISMA
*during task-dependent state visualisation*



Furthermore, locations of process violations can be achieved by sub-premises of rules represented by icons. These sub-premises containing process variables and values margins can be selected to activate topological views, and so to go to the location of the components that must be controlled and handled. As mentioned above, this state visualisation is task-dependent. This means that after completion of correct actions, a process violation will disappear although the state variables are still have undesirable values.

## Evaluation

The usability of this human-machine interface was evaluated in a comparative investigation (Kopecny, 1996). Two other user displays using different concepts were used for the evaluation after software and cognition-ergonomic aspects, which reflect the requirements at man-machine interfaces for dynamic processes. The first user display is oriented on the guideline VDI/VDE 3695 (1986) and structures the information topological and hierarchical such as outlines, sub-systems, areas, groups and measurement-points. The other user display visualises functional coherence and is based on the multilevel flow modelling theory (MFM) by Lind (1988, 1993). These user displays were implemented to be acquainted with the status of man-machine interfaces in process control and for evaluation purposes. The results of the laboratory experiments show that approximate knowledge-based process visualisation is very suitable for the support of human operators during their control and monitoring activities (see Ali, 1998; Kopecny, 1996).

## Conclusion

This contribution presents a new kind method for the design of human-machine interfaces in process control. By means of this method a graphical user display called *PRISMA* was developed and compared with other two displays. Through these displays that based on different design philosophies, the same technical process *distillation column* can be controlled and monitored. The purposes for developing these user displays were to analyse supervision problems in process control as well as to use them as reference systems in the evaluation mentioned above. The visualisation technique achieved through this method is called *approximate knowledge-based process visualisation*. The main goal of this visualisation is the optimum integration of the operator in the whole control loop of the human-machine system. This will lead to better work satisfaction of the human as well as more security and economic efficiency.

## References

Ali, S. (1998). Approximative wissensbasierte Prozeßvisualisierung auf Basis der Fuzzy-Logik. Dr.-Ing. Dissertation. Universität-Gh Kassel

Ali, S. (1997). Wissensbasierte Prozeßvisualisierung mit Fuzzy-Logik. In: K.-P. Gärtner (Hrsg.), Menschliche Zuverlässigkeit, Beanspruchung und benutzerorientierte Automatisierung, pp. 183-196. 39. Fachausschußsitzung Anthropotechnik der (DGLR) am 21. und 22. Oktober 1997 in Karlsruhe. Bonn: DGLR, ISBN 3-922010-98-9

Funke, J. (1992). Wissen über dynamische Systeme: Erwerb, Repräsentation und Anwendungen. Berlin: Springer

Johannsen, G. (1993). Mensch-Maschine-Systeme. Berlin: Springer

Johannsen, G., Ali, S., Heuer, J. (1995). Human-Machine Interface Design Based on User Participation and Advanced Display Concepts. Post HCI 95 Conference, Seminar on Human-Machine Interface in Process Control, Kyoto, July 1995

Johannsen, G., Ali, S., van Paassen, R. (1997). Intelligent Human-Machine Systems. In: S. G. Tzafestas (Ed.), Methods and Applications of Intelligent Control, pp. 329-356. Dordrecht, The Netherlands, Kluwer Academic Publishers

Kahlert, J. (1995). Fuzzy Control für Ingenieure: Analyse, Synthese und Optimierung von Fuzzy - Regelungssystemen. Braunschweig: Vieweg

Kopecny, A. (1996). Untersuchung und Bewertung einer kognitiv-kompatiblen Mensch-Maschine-Schnittstelle für einen chemischen Prozeß. Unveröffentlichte Diplomarbeit am Labor für Mensch-Maschine-Systeme, Universität Gh Kassel

Lind, M. (1981). The use of flow models for automated plant diagnosis. In: Rasmussen, J. und Rouse W. B. (eds.) Human Detection and Diagnosis of System Failures. New York: Plenum Press

Lind, M. (1988). System concepts and the design of man–machine interfaces for supervisory control. In: L. P. Goodstein, H. B. Andersen, S. E. Olsen (Eds.), Tasks, Errors and Mental Models. Taylor and Francis, London, pp. 269–277

Lind, M. (1993). Multilevel flow modeling. AAAI '93 Workshop on Functional Reasoning. Washington, July 9–15 1993

Matern, B. (1984) Psychologische Arbeitsanalyse. Springer–Verlag, Berlin

Rasmussen, J. (1986) Information Processing and Human–Machine Interaction, North Holland, New York

Rasmussen, J. (1988) A cognitive engineering approach to the modeling of decision making and its organization, in W. B. Rouse (ed.), Advances in Man–Machine Systems Research, Vol. 4, pp. 165–243

VDI/VDE (1986) Preformatted displays on video display units for the control of process plants, Volume VDI/VDE Richtlinie (Guideline) 3695, VDI–Verlag, Düsseldorf

Zimmermann, H.–J. (1991). Fuzzy Set Theory and its Applications. Boston, MA: Kluwer Academic Publishers

# Evaluation of a Modern Approach to Process Visualisation using Multilevel Flow Modelling (MFM) and Ecological Interface Design (EID)

*Andreas Völkel*

## Abstract

The continual development of industrial processes implicates an increasing strain for the operators of such plants. There is also an increasing level of automation due to increasingly powerful and cheaper automation hardware. The consequence is a decreasing number of operators for driving a process with a concurrent rise of information that has to be observed by the separate operator (Thierfelder, 1997; Herbst and Rieger, 1997). The increased automation level involves a loss of manual skills in leading a process, while the area of responsibility for the operators increases (Reinig et al., 1997; Bainbridge, 1983). So there is the question whether newer modelling techniques like MFM (Multilevel Flow Modelling) or EID (Ecological Interface Design) can improve the controllability of industrial processes.

## Introduction

Machines should be adapted to the needs of man and not the other way round. A convenient configuration of the systems which perform the information flow in both directions (this is the interface between man and machine) can achieve this adaption. Newer modelling techniques were developed to realise the demand of a user centered modelling. One of these newer ways to model complex systems is the Multilevel Flow Modelling (MFM) by Lind from Denmark. Another modern modelling technique, the Ecological Interface Design (EID), comes from Kim Vicente from Canada. Both visualisations can be used for modelling a process at different levels of abstraction. MFM uses objects like goals, functions and physical components for the description of a system. EID applies the conversion of mathematical relations into geometric objects for the reproduction of a system where not only trivial relations are shown, but also more complex coherences, e.g. between fill and energy levels. Common visualisation techniques use the Single–Sensor–Single–Indicator (SSSI)–Philosophy (Goodstein, 1981). Physical information is shown on displays (e.g. pointer and scale). This assumes a strongly distinct capability of deductional thinking by the operator, i.e. psychological processes running on a high cognitive level. Furthermore, the models based on

Andreas Völkel: Late in 1996 I began writing my diploma thesis “Consistency Check of Process Data by Multilevel Flow Modelling” at the institute of Professor Dr.-Ing. Johannsen. After finishing my diploma thesis I worked as a consultant for data processing and programmer of databank systems. However, my objective was to work in the field of man-machine-systems again. Parallel to the consultant work a first research application about process visualisation was developed, highly supported by Prof. Johannsen at diverse weekends, and finally filed to the DFG (National Research Foundation). Since then this research project has been finished successfully. Presently I work as a scientific assistant in a DFG-Project with the objective to provide interfaces adapted to individual operators using evolutionary optimisation.

logical or mathematical behaviour do not support more than one level of abstraction for modelling the process. But designer, operators and systems engineers often discuss the goals of a process and the means for reaching these goals in addition to components needed (Vicente and Rasmussen, 1990). The mentioned newer modelling techniques shall reduce the instance of thinking, so operators can concentrate on the important tasks and shall provide more than one abstraction level for modelling a process.

## The modelling techniques

Additionally to the modelling techniques mentioned above, MFM and EID, a third way of modelling was used as kind of a reference. This was the common topological view (TOP) on a process.

## Multilevel Flow Modelling MFM

The Multilevel-Flow-Modelling MFM suggested by Lind (1990), deals with the representation of a system by multiple descriptions at different abstraction levels. A system will be described by terms of goals, functions, and physical components. At the same time, each of these descriptions can be treated on different hierarchical decomposition levels. The goals are the purpose or the intentions of the designer the system was made for. For the modelling of the system's functions, simple functional perceptions are used, which relate to the control of linked mass, energy or information flows. The suggested functions are sources, transports, balances, storages, barriers, sinks, and, in addition to information flows, observers, decisions, and actors. All types are realised by symbols as part of a graphical representation language. They can link together into structures in consideration of different syntax rules. The symbols do not represent physical components as in common RI–Pictures, but show functional coherences. The physical components realise the flow functions in MFM, and by implementation of the functions, a goal can be fulfilled (Lind, 1990). According to Larsson (1992) MFM shows the functional structure of a system as a number of flow structures relating to each other at different abstraction levels. The abstraction levels again are connected by different relations (e.g. achieve relations or conditional relations). Table 1 shows the MFM objects, their meanings, and an example for the object.

*Table 1: MFM Objects: Goals and flow functions*

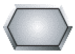
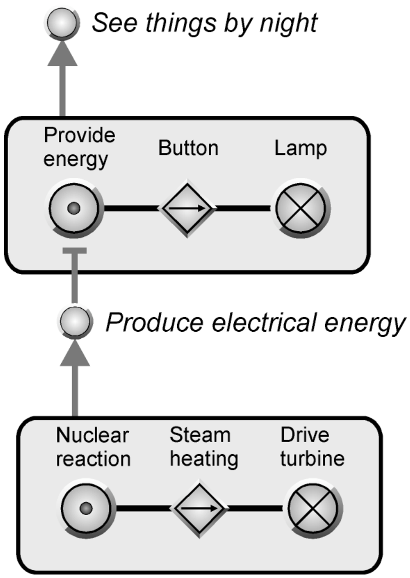
| Symbol | Indication | Meaning | Example |
|---|---|---|---|
|  | Goal | Purpose a system was made for | See things by night |
| Flow functions for mass, energy, and information flows | | | |
|  | Source | Infinite output | Provide energy |
|  | Transport | Transport between systems | Deliver mass |
|  | Barrier | No transport between systems | Do not deliver mass |
|  | Storage | Store mass, energy, or information | Save information |
|  | Balance | Equal input and output rates | Provide same in- and output |
|  | Sink | Infinite input | Extract energy from material |
| Flow functions only for information flows | | | |
|  | Observer | Bringing Observation to Information | Transform measured value |
|  | Decision | Decision making | Generate desired value |
|  | Actor | From Information to physical consequence | Transform information into action |
| Function for resource management | | | |
|  | Management | Organisation | Control a system |

Figure 1 shows a small example for an MFM-Model. The main goal of the modelled system is to see things by night. To achieve the goal, you have to implement some functions. First there must be energy (source), which can used by pressing a button (transport) and finally a lamp (sink) will be activated. The flow functions of these energy flow structure are linked to the main goal by a achieve relation. This means a goal is reached, if all flow functions of the linked flow structures are enabled and are working well. The source in Figure 1 is also linked to another goal, which means that you can only provide energy if there is a production of electric energy. This kind of connection is called condition relation and tells the user that the flow functions state depends on the goal's state. All flow functions can have such relations to goals. In the example the sub goal can be reached by another energy flow structure. Source is the nuclear reaction in a nuclear power plant. The heated steam transports the energy to a turbine, which transform the heat into electrical energy.

*Figure 1: Example for an MFM-Model*



## Ecological Interface Design EID

With the Ecological Interface Design (EID) developed by Vicente, there is another possibility to build cognition related man–machine–interfaces. The basis for EID are the action models for human information processing by Rasmussen (1983). The functions of a process will be visualised in EID by geometric figures of mathematical relations between the relevant process variables. These mappings show the influence of the different variables in a particular conveniently manner.

Figure 2 shows the steps for making an EID–model. First of all you have to describe a system by several equations for the values you are interested in (see upper, Figure 2). Second step is to generate the geometries for these values (see middle, Figure 2) and finally you have to link these geometries in the mappings (see lower, Figure 3).

On the upper horizontal edge of these mappings you can see the input, at the lower horizontal edge the output of mass and energy balances. These two lines will be connected, so the tendency of the variable can be shown. If the input is smaller than the output, the connecting line will have a negative gradient, which means a decrease of the variable shown in the vertical part (here a fill level). The same applies for energy balances. It is possible to merge mass and energy mappings in a third object. This shows the influence of the variables among each other. Additionally, EID uses common symbols for the equipment of a system (e.g. pumps, valves, etc., see TOP Table 3). With these symbols an operator can control the process and see the consequences of his actions very fast. In contrast to MFM, EID does not separate mass and energy flows, but shows them in views related to each other. In case of direct influence between mass and energy flow, this can be an advantage in monitoring their effects. The papers of Sakuma et al. (1995), Watanabe (1995), Xinyao et al. (1997), and van Paassen (1997) show an increased interest for EID.

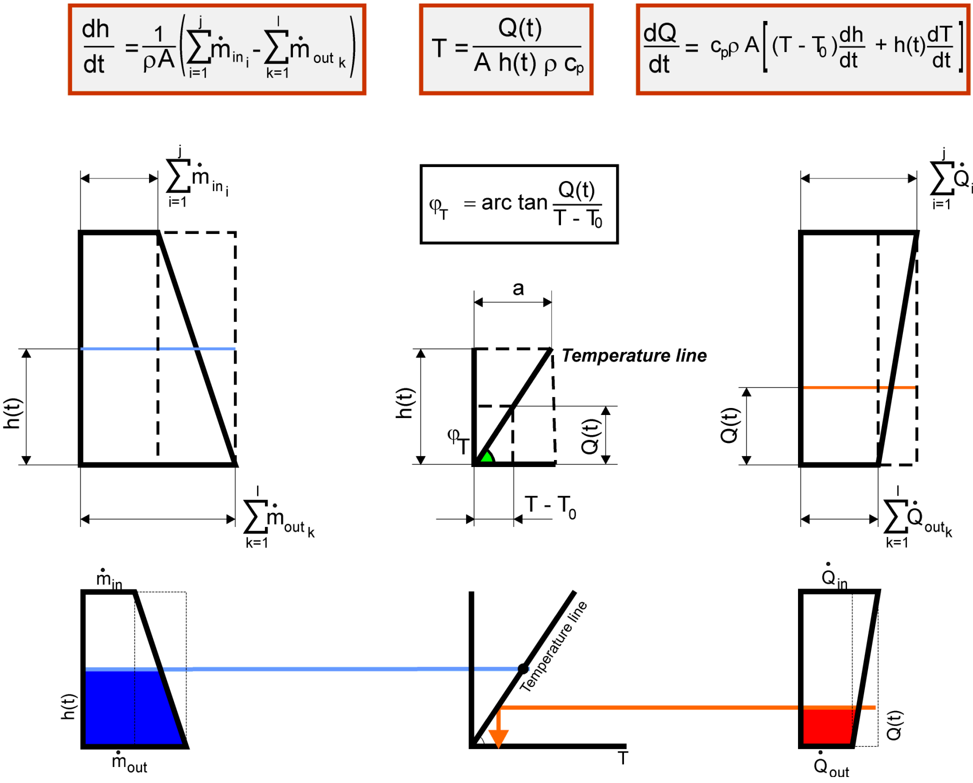
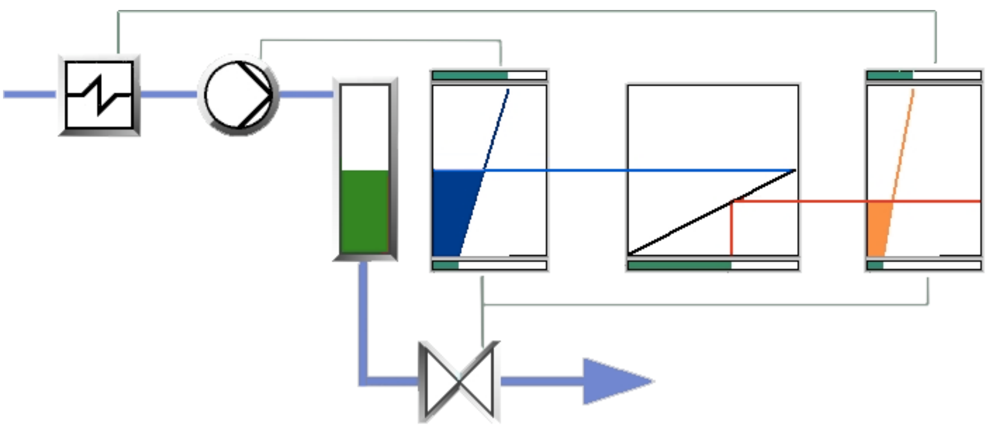



*Figure 2: Modelling with EID*

In Figure 3 you can see an example for an EID model. The example shows the topological symbol of a buffer with one input and one output. The input depends on the pumps (above the buffer) state, the output on the opening of the valve (behind the buffer). Additionally there is a heat exchanger (first component left), which decides about the energy input. The energy output depends on the mass flow: the more mass is lost, the more energy is lost.

The small lines between the topological and the EID objects show which topological object influences which EID object.

*Figure 3: Example for an EID-model*

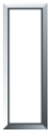


## Topological View (TOP)

The topological view (TOP) is the common visualisation of industrial processes. The TOP interface shows the plants consisting components and subsystems. The components like pumps, valves, heat exchangers are visualised as DIN–Symbols[2]. Topological interfaces strive to reproduce the configuration of the systems components as they are positioned in the real plant. So topological views also include a kind of geographical information. Table 2 shows the TOP objects.

[2] DIN: Deutsches Institut für Normung, Symbols: DIN 28004

*Table 2: TOP objects*

| Symbol | Indication | Function | Example |
|---|---|---|---|
|  | Pump | Transport material | |
|  | Valve | Regulate flow | |
|  | Heat ex-changer | Heat/Cool material | |
|   | Controller | Control a value | Flow |
|  | Buffer | Store material | |
| | Pipeline | Transport material | |
|  | Display | Show values | Temperature |

## Used Process: The Distillation Column

The process used is the simulation of a chemical distillation column. Here a mixture made of two elements (benzol and toluol) has to be separated. The operator has to control different components to maintain a certain temperature distribution to get the elements with proper quality and with a sufficient amount. The input provides the mixture from a previous process, a column in the middle separates the mixture in Benzol and Toluol, which will be extracted from the plant at the upper (plant's head: Benzol) and lower parts of the plant (plant's bottom: Toluol). To provide and maintain the quality required, some head and bottom product will be lead back into the column.

## Developed Interfaces

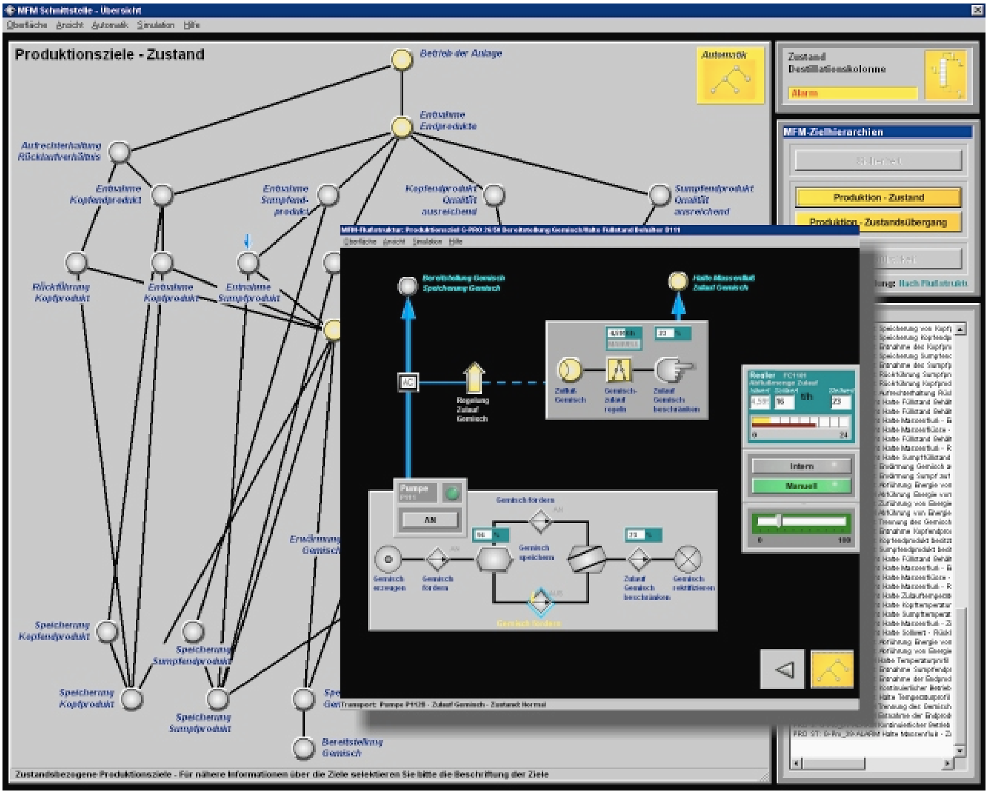
For testing if MFM or EID or both or different combinations can improve the manageability and the controllability of complex industrial processes, several interfaces were developed by the use of the C++–class library *KogProVis*[3] (see figures below). KogProVis allows the representation of a process with MFM, EID, and in a common topological view (TOP) at the same time. So experiments can be performed with a view to verify or refuse the thesis of an improvement through MFM and / or EID.

[3] German: Kognitionsbezogene Prozeß-visualisierung – Cognition Related Process Visualisation – (developed by the author using the C++–Builder from Borland).

## MFM Interface

In the background of Figure 4 you can see the production goal hierarchy of the modelled process. A textual description belongs to every goal. Furthermore, each goal will be coloured depending to its state. By selecting a goal the corresponding flow structure appears on the screen. The components to realise the flow functions appear by selecting the different flow function symbols.

*Figure 4: KogProVis: MFM–Man–Machine–Interface*



The main goal in the production hierarchy "Operation Plant" is coloured in yellow, which means that here is an alarm. Also a second goal "Extract end products" is on alarm state. The achievement of both goals depends among other things on the state of the flow function "Deliver mixture". These flow functions are related to the goal "Provide mixture" by a condition relation, so the belonging flow structure can be called. The figure shows the corresponding mass and information flow structure. The observer and the decision are also coloured yellow, because the mixture mass flow is too low. By using the function "Regulate mixture input" (realised by a valve), this error can be corrected.

## EID Interface

Figure 5 shows the main view of the EID interface. The plant is visualised with all subsystems in topological view and additionally with EID mappings for all important variables. The smaller window shows the input of mixture as an EID visualisation. The EID mappings show a mass balance (left), energy balances (right), and the mixture temperature (middle).

*Figure 5: KogProVis: EID-Man-Machine-Interface*

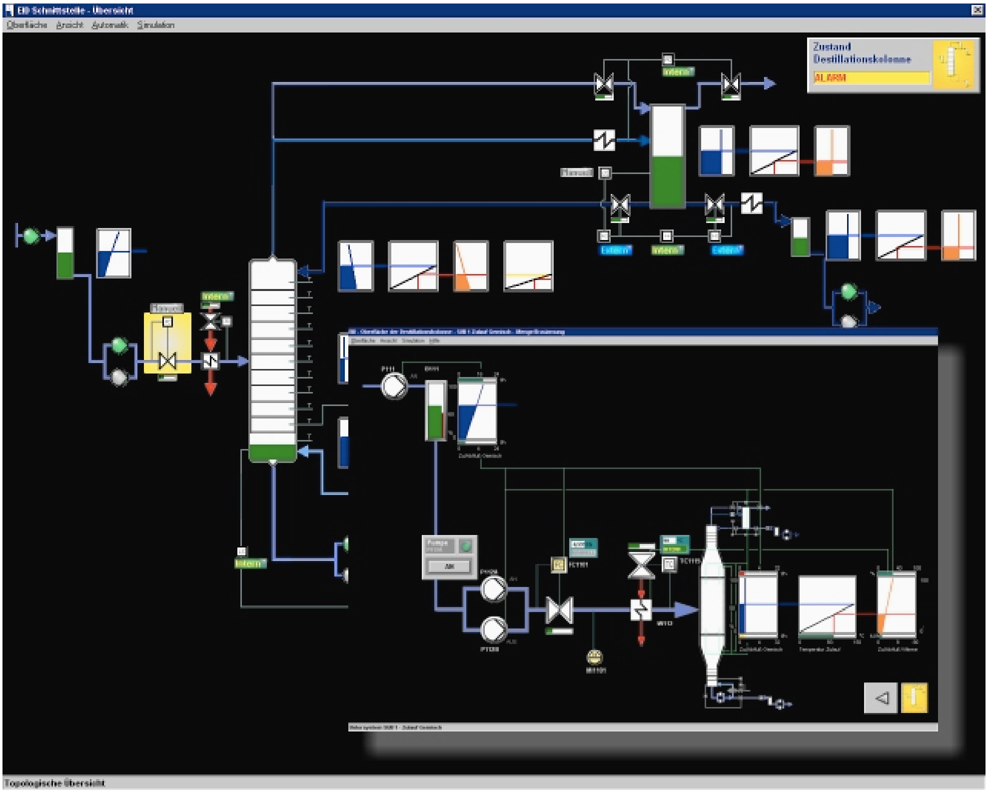


Figure 5 shows the same view of the plant like Figure 4, only in the EID interface. The valve to regulate the mixture input is too low. This can be seen by the subsystem and the controller coloured yellow or by regarding the mappings on the very left in the main and the sub view. Both mappings show the same: a larger input than output for the mixture buffer (increasing tendency for the fill level). The small lines show the influence of the valve to the mass output. By regulating the valve opening, this error can be corrected.

## TOP Interface

The TOP main view is shown in the background. It is equivalent to the EID main view, only without the EID mappings. Additionally there is textual information about the subsystems` states. The smaller window in front also shows the input of mixture. The components of these subsystems heat the mixture and transports it to the column.

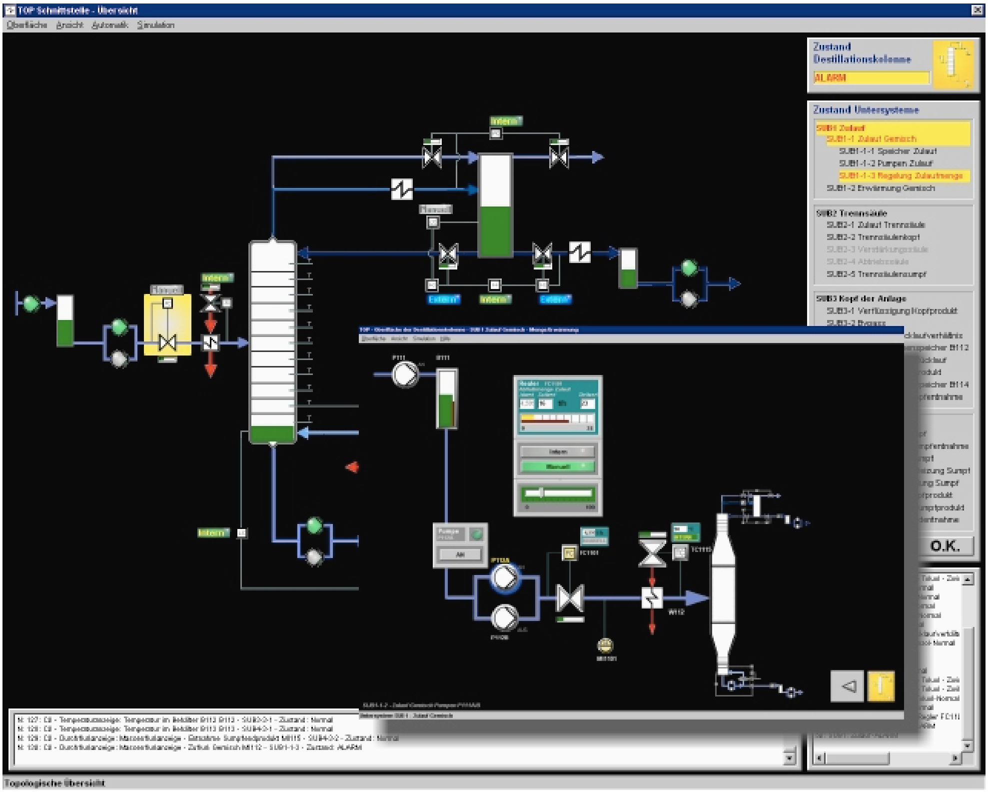



*Figure 6: KogProVis: TOP-Man-Machine-Interface*

Again, the TOP interface in Figure 6 shows the same error as the Figures 4 and 5. The view is the same as the EID view, except without the mappings. The user can only recognise the error by the yellow coloured objects in the main and the sub view.

## Experiments

To answer the question what is best for controlling the class of the modelled plant – MFM, EID, TOP, or combinations of them – several experiments were performed and are still running. In the experiment the probands have to resolve five scenarios for each interface and interface combination. After finishing the scenarios, the probands were asked to answer several questions in relation to the design of the interface and its modelling technique.

### Experimental Environment

For providing the interfaces three computers are used that are linked together in an intranet. Another linked computer calculates the simulation data, controls the scenario run and the evaluation.

### Independent Variables

The developed interfaces, the probands and the performed scenarios are the independent variables. The interfaces were (and will be) tested on their own and in different combinations, as following:

- G1: MFM
- G2: EID
- G3: TOP
- G4: MFM / EID
- G5: MFM / TOP
- G6: MFM / EID / TOP

The combination of EID and TOP would not make sense because EID includes TOP.

The probands were (and will be) students and employees of technical and non-technical faculties, and operators of real plants. Non-technical probands were chosen because of their impartiality. Technicians often know the TOP-view, so they may prefer this view because they have seen it before.

Another independent variables are the scenarios in the scenario run. These scenarios have been developed to reduce the effort of the probands in learning the process and the different modelling form. The performed scenarios are as following:

- S1: Malfunction flow controller for mixture input
- S2: Malfunction flow controller in the head back stream
- S3: Pump head output disturbed
- S4: Malfunction temperature controller in bottom heating
- S5: Malfunction heat exchanger in cooling head input

Each scenario takes 150 seconds, the failure occurs after 20 to 25 seconds. The probands have to resolve the incoming failure and bring the plant back to normal state.

## Dependent Variables

The dependent variables in the experiment persist of two parts: an objective and a subjective part. The objective part deals with the actions of the user on the interface. The subjective part asks the proband about his (subjective) evaluation of the interface. The best value for the evaluation values is 1, the worst is 0, excepting the abstraction level (1: concrete up to 6: abstract).

### Objective Evaluation

The objective part of the experiment contains the following terms:

Efficiency $x_{eff}$

Reciprocal numbers of actions $\eta_H$ during a scenario times the reciprocal execution time $t_A$ for solving a scenario:

$$x_{eff} = \frac{1}{2}\left(\frac{1}{\eta_H} + \frac{1}{t_A}\right)$$

Standardised execution time $x_{tA}$

Time for solving the confronted task in the scenario (1: best, 0: worst)

$$x_{t_A} = 1 - \frac{t_A}{t_{A_{\max}}}$$

Scenario solving $x_S$

Could the proband solve the confronted tasks in the scenario run?

$$x_S = \frac{N_{S_{sol}}}{N_{S_{\max}}}$$

$$N_{S_{sol}} = \sum_{i=1}^{N_{S_{\max}}} S_{sol_i} \qquad S_{sol_i} = \begin{cases} 0 : \text{Proband did not solve the scenario} \\ 1 : \text{Proband solve the scenario} \end{cases}$$

The objective part runs during the scenarios (recording of proband actions) and after the end of the scenario (calculation of the efficiency).

**Subjective Evaluation**

The subjective part of the experiment follows after the end of the last of the five scenarios. The probands have to answer different questions by choosing an evaluation on various seven–point–scales and percent–scales. This subjective evaluation also runs on the computer. The criteria are as follows:

Transparency $x_T$

The proband shall say if the interface informed him at every time clearly about the systems state.

Support $x_{SP}$

The support for controlling the plant. The proband has to say if the interface assisted him with correcting the incoming failure during a scenario.

Navigation $x_N$

Orientation in the interface is questioned here. How easy could the proband find information and system components?

Error Management

Error correction and compensation is very important in driving and monitoring technical systems. For our experiment the three phases were examined by several questions:

- Error detection $x_{E-DE}$: Finding an error.
- Error diagnose $x_{E-DG}$: Error classification.
- Error correction $x_{E-C}$: Correct or compensate an error.

Structure $x_{ST}$

Structure of the interface, e.g. stronger orientation to man or technique, support through the interface to task solving.

Modelling $x_M$

Questions about interface characteristics, recognition of the meaning of the graphics (e.g. for MFM goals, flow functions, for TOP components, and for EID mappings).

Interface $x_I$

Questions to the design, e.g. object sizes or colours.

Strain $x_{SR}$

Probands perception of the strain during the scenarios.

Confidence $x_C$

Confidence of the proband to the interfaces.

Fun $x_F$

A very subjective criteria, if a proband had also has fun controlling a process via the interface.

Abstraction level $x_{AL}$

The proband has to say whether the interface is more abstract or more concrete.

## Course

The course of the experiment is the same for all interfaces and interface combinations. At the beginning of the experiment the proband gets an introduction to the process. The purpose, functions, subsystems and the equipment are explained. After explaining the process the introduction to the modelling technique follows. Next step is to explain the interface, e.g. state visualisation, navigation, controls, displays, etc. Now the proband gets to know the interface by himself. In a kind of free flight the proband can test the whole interface and discuss questions. The last step before the real experiment includes two test scenarios, where the proband receives an impression of the following scenario run. A message appears on the screen, which informs the proband about the beginning of the real experiment. A short text explains the further course, and after confirming the reading of this text, the scenario run starts. It takes 750 seconds (12 1/2 minutes) to complete one scenario run. The evaluation of the interface starts shortly after finishing the scenario. Every proband is asked to test all interfaces and interface combinations. The order of the interfaces and interface combinations and the scenario order in the scenario run are permuted. The end of the experiment is a discussion with the proband about the interfaces.

## Results

Unfortunately the results are not complete because the experiment is still running. So please remember that when regarding the following results.

### Objective evaluation

Table 3 shows the results of the objective part so far (nine probands).

*Table 3: Objective evaluation – results*

| | G1 | G2 | G3 | G4 | G5 | G6 |
|---|---|---|---|---|---|---|
| $x_{eff}$ | 0.081 | 0.113 | 0.115 | 0.100 | 0.118 | 0.106 |
| $x_{tA}$ | 0.485 | 0.698 | 0.784 | 0.613 | 0.698 | 0.706 |
| $x_S$ | 0.622 | 0.867 | 0.867 | 0.733 | 0.822 | 0.822 |

The MFM / TOP–Interface shows the best results in the efficiency criteria, the TOP interface in the execution time. EID and again TOP are best in solved scenarios. The good results for the combinations could be explained with the incompleteness of the experiment. Until now the combinations were the last ones in the order of the interfaces. The experiments later on will compensate this effect of order. MFM is worst for all interfaces. The reason for this may be the abstract visualisation of MFM. Most of the probands said they were confused during the scenario. They had difficulties extracting the information out of the interface and to understanding clearly what they have seen. These bad results in the objective part of MFM can also be found in the evaluation of the subjective part of the experiment of MFM. The results so far of the subjective part are shown in Table 4.

*Table 4: Subjective evaluation – results*

| | G1 | G2 | G3 | G4 | G5 | G6 |
|---|---|---|---|---|---|---|
| $x_T$ | 0.684 | 0.786 | 0.784 | 0.735 | 0.731 | 0.731 |
| $x_{SP}$ | 0.463 | 0.667 | 0.648 | 0.685 | 0.648 | 0.629 |
| $x_N$ | 0.561 | 0.728 | 0.757 | 0.630 | 0.667 | 0.641 |
| $x_{E-DE}$ | 0.519 | 0.676 | 0.648 | 0.731 | 0.685 | 0.731 |
| $x_{E-DG}$ | 0.537 | 0.648 | 0.648 | 0.648 | 0.654 | 0.716 |
| $x_{E-C}$ | 0.401 | 0.574 | 0.617 | 0.642 | 0.636 | 0.660 |
| $x_{ST}$ | 0.392 | 0.588 | 0.611 | 0.548 | 0.556 | 0.559 |
| $x_M$ | 0.478 | 0.551 | 0.612 | 0.514 | 0.545 | 0.547 |
| $x_I$ | 0.639 | 0.750 | 0.738 | 0.692 | 0.689 | 0.707 |
| $x_{SR}$ | 0.384 | 0.599 | 0.613 | 0.628 | 0.627 | 0.522 |
| $x_C$ | 0.488 | 0.686 | 0.761 | 0.747 | 0.681 | 0.723 |
| $x_F$ | 0.422 | 0.631 | 0.754 | 0.723 | 0.751 | 0.761 |
| $x_{AL}$ | 4.778 | 2.889 | 2.667 | 2.889 | 3.111 | 2.667 |

The best results for transparency is reached by the TOP interface, worst is MFM. That is surprising because MFM just wants to show a system in a transparent way using a man centered design of goals and functions. The reason may be the confusion by using MFM (see also objective part of the experiment).

The combination MFM / EID gets the best evaluation for task support, MFM is worst. This contradiction can be explained with the stronger use of EID (72%) compared to MFM (28%) during the experiment.

For the navigation criteria the TOP interface shows the best values again, MFM again the worst. The visualisation in TOP and EID with main system and zooming into the subsystem is better for navigation than the goal hierarchy and flow structures of MFM.

The error detection is best with MFM / EID and the MFM / EID / TOP combination. The MFM / EID / TOP–combination gets the best evaluation for error diagnose and error correction is best with the MFM / EID / TOP–combination again. MFM gets the worst evaluations for all parts of the error management. This relates to the other evaluations for MFM. Regarding the whole error management, it is remarkable that the combinations get the best values and the isolated interface gets the worst ones. The probands said they can monitor the process in one survey view of one interface and act in the other in the lower levels.

The evaluation for the interface objects is best for EID, MFM worst. The values for the combinations are as expected in between. The best value for the interface structure gets TOP, last is MFM. The modelling technique of TOP again is evaluated as best, MFM is worst. The felt strain during the scenarios was lowest for the MFM / EID combination and highest for MFM. The MFM / TOP combination gets the second place, so combinations of two interfaces are best for low strain. The combination of all interfaces increases the felt strain. The probands did not know where to look; here the isolated interfaces were better (except MFM). The best confidence value gets TOP, the lowest MFM. This corresponds with the other evaluations. The probands had most fun with TOP, less with MFM. And finally the abstraction level: MFM gets as expected the highest value, TOP the lowest.

By regarding the result, it can be remarked in a simplified way that the higher the abstraction level is, the lower the evaluation is. MFM always gets the worst evaluation, as well in the objective part as in the subjective. The probands said they had too much to read in the goal hierarchy and did not recognise the symbolism. The TOP interface evaluation is mostly best, because the probands liked the segmentation in main and sub view. For the same reason EID gets good values, but the mappings did not increase the evaluation for EID. Finally the combinations were best for error management because of the multiple views to the plant.

## References


Bainbrigde, L. (1983). Ironies of automation. Automatica 19(6), pp. 775–779

Goodstein, L. P. (1981). Discriminative display support for process supervisors. In: Human Detection and Diagnosis of System Failures (J. Rasmussen and W. B. Rouse, Eds.). pp. 21–36. Plenum Press. New York

Herbst, L. and Rieger, W. (1997). Modernste Prozeßvisualisierung im Kraftwerk Schkopau. ABB Technik (1), pp. 13–18

Larsson, J. E. (1992). Knowledge–Based Methods for Control Systems. PhD thesis. Department of Automatic Control, Lund Institute of Technology

Lind, M. (1990). Representing goals and functions of complex systems: An introduction to Multilevel–Flow–Modeling. Technical Report 90–D–381. Institute of Automatic Control Systems, Technical University of Denmark van Paassen, R. (1997). Process Displays based on Multilevel Flow Modelling MFM and Ecological Interface Design EID, Technical Report MMS-16. Institute of Measurement and Automation, University of Kassel

Rasmussen, J. (1983). Skills, rules and knowledge: signals, signs, and symbols, and other distinctions in human performance models. IEEE Transactions on Systems, Man and Cybernetics 13, pp. 257–266

Reinig, G., P. Winter, V. Linge, and K. Nägler (1997). Trainingssimulatoren: Engineering und Einsatz. Chemie Ingenieur Technik 69(12), pp. 1759–1764

Sakuma, A., J. Itoh, E. Yoshikawa, and K. Monta (1995). Simulation study of an ecological interface for nuclear power plants.
In: Symbiosis of Human and Artifact, 6th International Conference on Human-Computer Interaction. Tokyo, Japan

Thierfelder, H. G. (1997). Mit neuester Technik bestehende Kraftwerke modernisieren. ABB Technik (2), pp. 15–24

Vicente, K. J. and J. Rasmussen (1990). The ecology of human-machine systems II: mediating "direct perception" in complex work domains. Ecological Psychology 2(3), pp. 207–249

Watanabe, O., K. Takamura, Y. Fujita, and Y. Hayashi (1995) Evaluation of ecological interface design. In: Symbiosis of Human and Artifact, 6th International Conference on Human-Computer Interaction. Tokyo, Japan

Xinyao, Y., E. Lau, R. Khayat, K. J. Vicente, and M. W. Carter (1997). Ecological interface design & long-therm adaptation: information, coordination, & execution-driven control.
In: Proc. of the International Symposium on Artificial Intelligence, Robotics and Intellectual Human Activity Support for Nuclear Applications. Saitama, Japan

# Vivid Views on the Technical System – the Virtual Process Visualisation

*Carsten Wittenberg*

Carsten Wittenberg: I met Gunnar for the first time during an interview when I was applying for a position at his Laboratory. During the following five years he taught me the “secrets” of human–machine systems und guided me through the shallows of writing my doctoral thesis. After finishing my doctoral thesis, I moved from Gunnar’s Lab over short research step at Toshi Inagaki’s Lab in Tsukuba, Japan to an industrial User Interface Design lab at Siemens, Munich. Fortunately, we meet at the usual HMI conferences in regular intervals.

## Abstract

This paper presents the Virtual Process Visualisation (ViProVis) method for supervisory control of technical systems, which contains the three pillars Virtual Process Elements, Target and State Visualisation and Task–oriented Structure. Based on this method, two interfaces for different applications are developed. In the experiments, these graphical user interfaces are be compared to and evaluated against conventional topological interfaces.

## Introduction

Complex, dynamic industrial plants are still monitored and controlled by human operators in control rooms. Increasing requirements in respect of quality, economics and ecology, and increasingly efficient and inexpensive automation systems, lead to an increasing level of automation in such technical systems. As a result, the number of operators decreases, while the amount of process information that has to be monitored and controlled increases. Operators have to deal with a flood of information. Nowadays, several processes may be managed centrally from one control room, using computer–aided control systems. Conditional upon the information preparation, the operator becomes divorced from the process. Computer monitors are used to show a wealth of process information on a very limited space. However, identifying the relevant process variables from among the large number of information items is important (Johannsen, 1993). The operator can be assisted in this situation by a graphical user interface to the technical system, suitably developed to accommodate human capabilities.

The design of human–machine interfaces must be such as to assist the human information processing – both in terms of the perception of information and also in action planning and problem solving.

This paper describes the Virtual Process Visualisation concept (Wittenberg, 1997, 1998, 1999, 2001), which was developed during the author’s time as a research assistant at Gunnar Johannsen’s Laboratory in Kassel.

## Requirements for process visualisation

Operators monitor and control the technical systems through the process visualisation. Most of the information is presented purely visually, on various computer displays. The process visualisation in combination with the displays are used as a window on the process. Depending on the quality of the information presentation, the operator is assisted to a greater or lesser degree in her / his daily work. An ideal process visualisation can be described as a "transparent window" on the process.

### Action models of human behaviour

On the basis of different action models of human behaviour (e.g. Rasmussen, 1984; Norman, 1986), the various steps in the operators' actions can be described in a very simplified form:

- The operator observes the process information, interprets this information and deduces the state of the (sub)process.
- The operator compares this actual state with the optimal state – the target. If there is a relevant deviation between the actual state and the target, the operator realises that action is required.
- In the last step, the operator plans and performs the necessary set of actions.

A user-centred process visualisation concept should support these steps, and hence the operator performing her / his tasks.

### Picture Superiority Effect

It is a well-known psychological fact that humans process pictorial information faster and more easily than textual information. These differences are described very well by the so-called multimodale model. This model describes different memory areas, which in each case are dependent on the modality of the initiating stimulus and possess very different characteristic abilities. The advantages of pictorial information – the so-called *Picture Superiority Effect* (Engelkamp, 1991) – are determined by this. Following that idea it should be advantageous if the process information is coded pictorially.

### Mental Model

Correct action planning by the operator is based on the mental model. The planning of action steps can be described as a dynamic cognitive simulation of the mental model. As with simulations of mathematical models on computer systems, this cognitive simulation is repeated iteratively, with the initial parameters changed each time, until a satisfactory result is achieved. The process visualisation must make available the information necessary for the operator to form a correct mental model, based on system and process identification. In addition, since a mental model is usually characterised by strong symbolism, support for the model should be based on such pictorial visualisation (Dutke, 1994).

## Information Structure

The cognitive capacity of humans – including human operators in process control – is limited. Complex technical systems like production processes usually contain hundreds or thousands of items of information. To ensure that the operator can control a complex technical system in every critical or non-critical situation, the process information must be structured in a function-oriented way. This enables a transparent presentation of the technical process.

## Virtual Process Visualisation

The Virtual Process Visualisation is a concept, which deals with the above problems by means of a special visualisation technique, derived from modern computer graphics. This type of visualisation can be used to show various kinds of relationships (even time-dependencies). The entire process is represented in a highly pictorial and transparent way.

There are three elements to this visualisation concept:

- Virtual Process Elements
- Target and State Visualisation
- Task-oriented Structures

These components of the concept are described below.

## Virtual Process Elements

The individual process units are implemented as so-called virtual process elements. Based on a typical member of the group of items concerned, a visual object is developed.

All these graphical objects have been developed to give a consistent presentation of information and consistent interactions. In accordance with the idea of direct manipulation, operators interact directly with the process items. This visualisation concept is expected to be efficient, with the process variables and the relationships between process items being visualised. Spatial variables – such as fill-up levels and flows – are shown directly, others are coded using colour and shape.

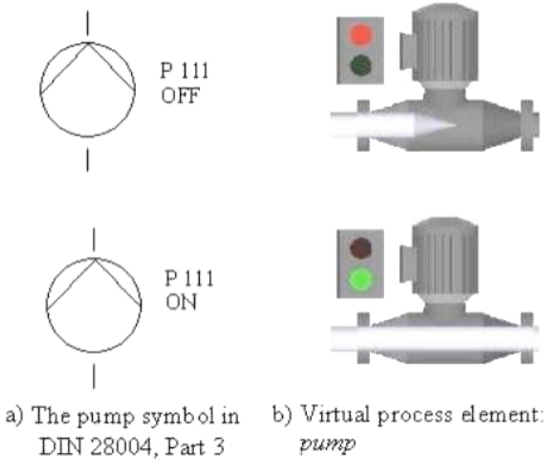



*Figure 1: Pump symbols*

Figure 1 shows the conventional DIN symbol for a pump and the corresponding Virtual Process Element.

## Target and State Visualisation

Subtasks are defined as appropriate for each higher-level function, and are associated with appropriate targets. Each subtask is associated with a specific process view, which includes the process items, the process variables and the relationships between them. A higher-level overview of the process shows the states of the system and the subtasks. The view of each subtask shows the achievement of its targets, the necessary process values, and the statuses of the process items. Because pictorial methods cannot be used to represent purely quantitative data, the process values are presented qualitatively. Threshold values and setpoints facilitate the identification of current process conditions. In the concept presented in this paper, the threshold values and setpoints are only displayed when the associated process values or process items are in abnormal states. This limits the volume of information to the essential minimum.

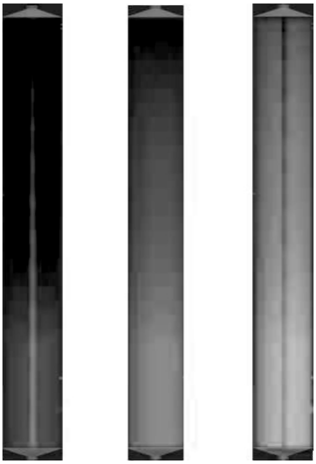


*Figure 2: Visualisation of the actual and desired temperature distribution (T) in a distillation column (Wittenberg, 2001) (left: actual T lower than desired T; centre: actual T = desired T; right: actual T higher than desired T)*

Figure 2 shows the visualisation of the temperature distribution in a distillation column. A small coloured line represents the optimal distribution and is only visual in case of a temperature deviation.

Figure 3 shows the visualisation of the fill-up level in a reservoir. As above, a small line represents the target value (50%). This line is visible only if there is a deviation from the target value. The arrows show the direction of the necessary level change. Like the "target-line" these arrows are again only displayed if there is a deviation. The size of each arrow corresponds to the deviation from the desired fill-up level.

*Figure 3: Visualisation of the actual and desired fill-up level (L) (left: actual L lower than desired L; centred: actual L = desired L; right: actual L higher than desired L)*

## Tasks-oriented Structure

To reduce the problem solving space, the process is structured hierarchically by function. This hierarchy is based on operators' tasks, as determined in previous analyses, and the statuses of the process items concerned for the tasks. A special area on the interface shows the completion of the tasks. Each task is associated with targets. The level of achievement of the target is represented by coloured bars. The colour and length of the bars show whether a target has been achieved, is still within tolerance, or whether a warning or an alarm is present. From the length of a bar, the operator can determine how far the targets have been achieved, and if intervention is necessary.

## Applications

For the evaluation of the Virtual Process Visualisation concept interfaces for two different exemplary applications were developed and implemented.

## Distillation Column

As the first exemplary application an interface for the guidance of a distillation process for the separation of a benzene-toluol-mixture is introduced. The process consists of a column with 10 bubble trays, one buffer for the benzene-toluol-mixture, two buffers for the final products benzene and toluol, two heat exchangers for preheating the influx and heating the sump stream up as well as of three condensers for the cooling of the reflux and the final products benzene and toluol. Figures 4 and 5 show screenshots of the developed interface.

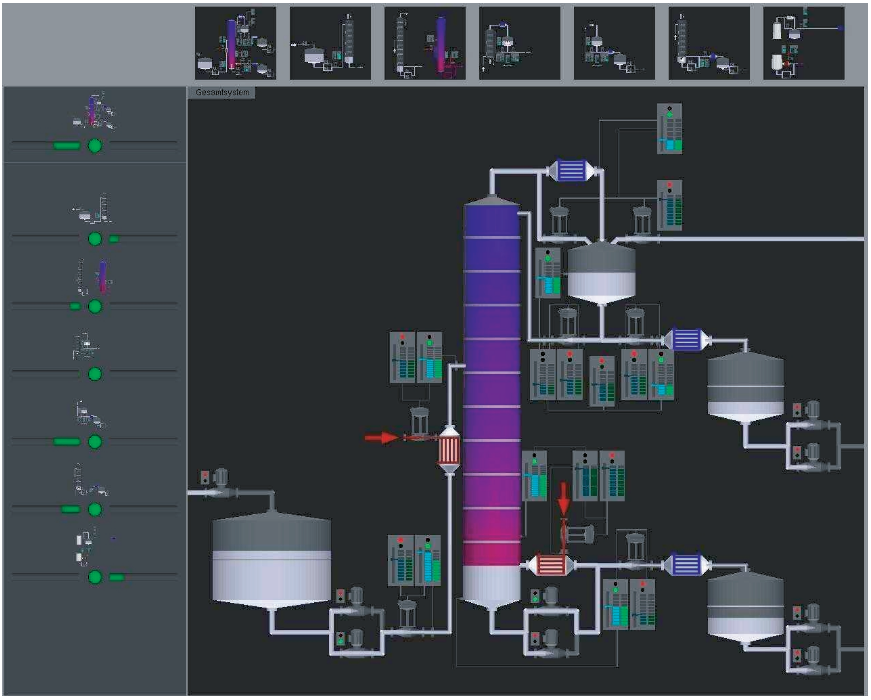
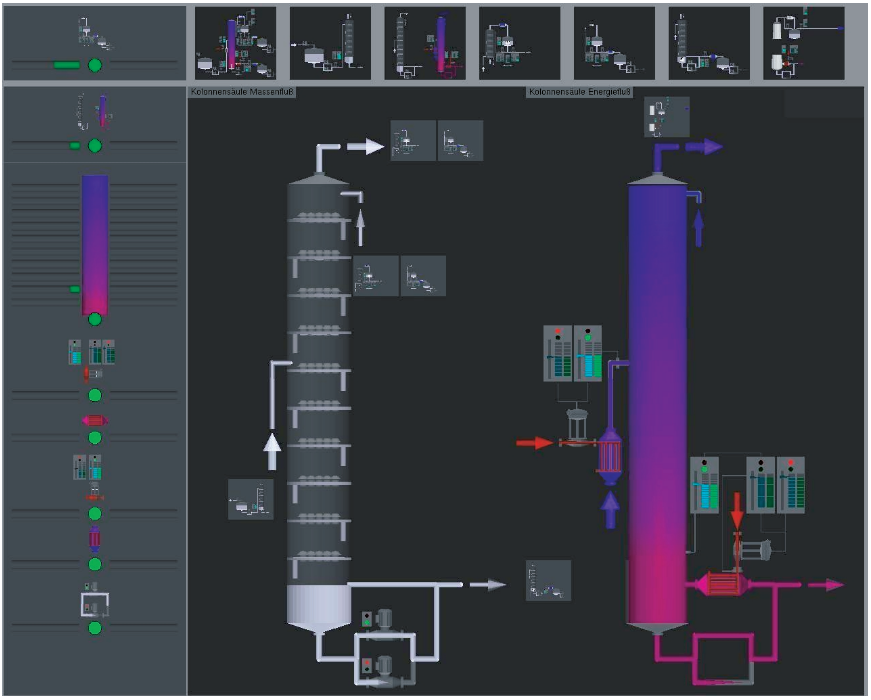



*Figure 4: Interface based on the Virtual Process Visualisation method for a distillation column – process view: overview (Wittenberg, 1999; 2001)*

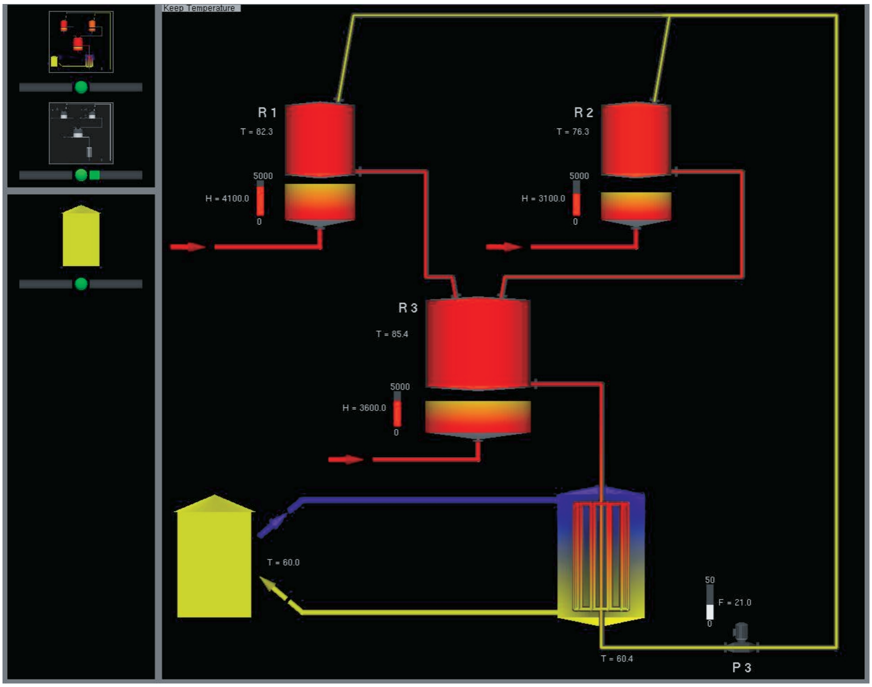
*Figure 5: Interface based on the Virtual Process Visualisation method for a distillation column – process view: distillation column (Wittenberg, 2001)*



## SCARLETT

A second interface was developed for an artificial microworld called SCARLETT (Supervisory Control and Response to Leaks: Tara at Tsukuba) during a fellowship of the Japanese Ministry of Science, Education, Sports, and Culture MONBU-SHO. SCARLETT is used for experimental research on supervisory control at the Laboratory for Cognitive Systems Science (University of Tsukuba, Japan) (Inagaki et al., 1998; Moray et al., 2000). This microworld represents a central heating system to maintain the temperature of an apartment complex (Figures 6 and 7). It consists of three heatable reservoirs, which are connected by a piping system. Using a heat exchanger the heat energy is passed on to the apartment complex.

*Figure 6: Interface based on the Virtual Process Visualisation method for a central heating application of an apartment complex (SCARLETT) – energy flow*



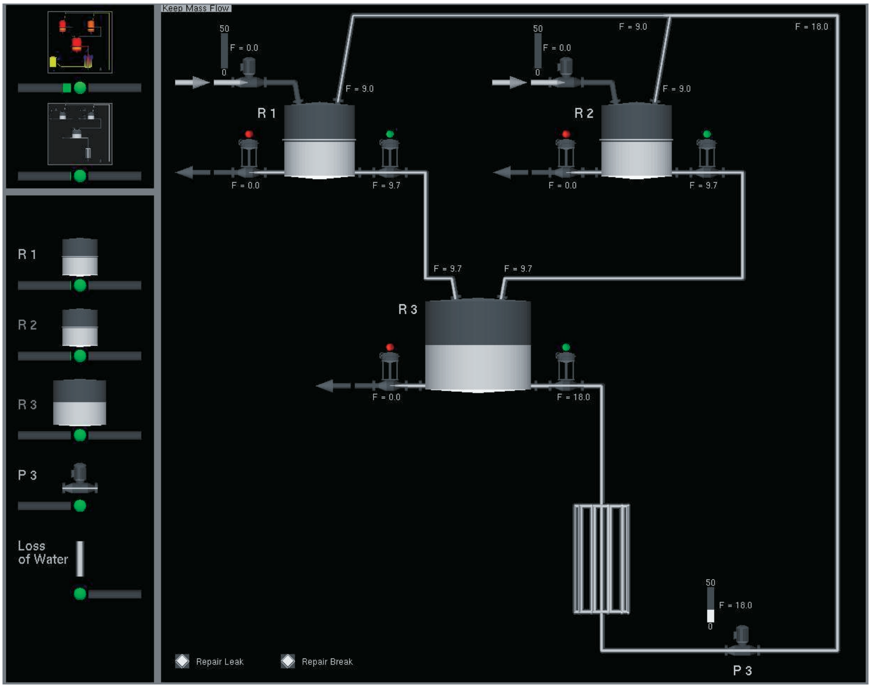



*Figure 7: Interface based on the Virtual Process Visualisation method for a central heating application of an apartment complex (SCARLETT) – mass flow*

## Experiments

In the experiments with both applications, the interfaces Virtual Process based on the Visualisation concept was be compared to and evaluated against conventional topological interfaces.

The experiments with the distillation process were performed at the laboratory of Gunnar Johannsen in Kassel. German graduate students hat to control the process. Different scenarios were implemented. After performing the experiments, the students filled out a questionnaire. Most of the requested variables were subjective items. The Man-Whitney-U-Test showed that the virtual process visualisation is significant better than the conventional topological interface (Kistner, 1999, Wittenberg, 2001).

Experiments with the SCARLETT-application were conducted in context of a MONBUSHO-fellowship in Japan. The subjects (Japanese graduate students) were split into in two groups. Each group started with a different interface. After the first stage of the experiment, the type of interface was changed for the second stage. Each stage contained five different scenarios, i.e. different initial values and a different desired temperature in the apartment block. As expected, differences were found in the time to respond to malfunctions, the number of undetected malfunctions, and in the mean error of the apartment block. An ANOVA was carried out, and showed that all these results are significant. A very interesting result was that the difference in the mean error of the temperature of the apartment complex depended on the sequence in which the interface types were used. The subjects who started with the interface based on the Virtual Process Visualisation method made a significantly lower error (including when they used the conventional interface).

## Conclusion

The experiments with both exemplary applications showed the ability of the Virtual Process Visualisation concept. These experiments verified the hypothesis that this visualisation concept for industrial process control is more descriptive, thus making it easier to comprehend the actual process state.

Further applied research will investigate the combination of such a descriptive visualisation concept with traditional concepts and with advanced technologies like acoustic devices.

## References

DIN 28004 Teil 3 (1988): Fließbilder verfahrenstechnischer Anlagen; Graphische Symbole

Dutke, S. (1994): Mentale Modelle: Konstrukte des Wissens und Verstehens. Göttingen: Verlag für angewandte Psychologie

Engelkamp, J. (1991): Das menschliche Gedächtnis: Das Erinnern von Sprache, Bildern und Handlungen. 2. Auflage, Göttingen: Hogrefe

Inagaki, T., N. Moray, M. Itoh (1998): Trust, Self-Confidence and Authority in Human-Machine Systems.
In: Proceedings IFAC Man-Machine Systems, Kyoto, pp. 431-436

Johannsen, G. (1993): Mensch-Maschine-Systeme. Berlin: Springer-Verlag

Kistner, J. (1999): Experimentelle Untersuchung von Mensch–Prozess–Schnittstellen. Unpublished Diploma Thesis, Systems Engineering and Human–Machine Systems, University of Kassel

Moray, N., T. Inagaki, M. Itoh (2000): Adaptive Automation, Trust, and Self–Confidence in Fault Management of Time–Critical Tasks. Journal of Experimental Psychology, 2000, Vol. 6, No. 1, pp. 44–58

Norman, D. A. (1986): Cognitive Engineering. In D. A. Norman, S. W. Draper (Eds.): User centered System Design, Hillsdale New York: Earlbaum, pp. 31–62

Rasmussen, J. (1984): Strategies for state identification and diagnosis in supervisory control tasks, and design of computer–based support systems. In: W. B. Rouse (Ed.): Advances in Man–Machine Systems Research, Volume 1, Greenwich: JAI Press, pp. 139–193

Wittenberg, C. (1997): Unterstützung der menschlichen Informationsaufnahme durch Prozeßvisualisierung mittels virtueller Prozeßelemente. In: K. P. Gärtner (Ed.): Menschliche Zuverlässigkeit, Beanspruchung und benutzerzentrierte Automatisierung, Bonn: Deutsche Gesellschaft für Luft– und Raumfahrt e.V. (DGLR), pp. 183–196

Wittenberg, C. (1998): Qualitative visualisation of a chemical process using the three–dimensional computer graphics. In: Proceedings of the 17$^{th}$ European Annual Conference on Human Decision Making and Manual Control, France, Valenciennes: LAMIH Laboratoire d'Automatique et de Mécanique Industrielles et Humaines, Université de Valenciennes, pp. 217–226

Wittenberg, C. (1999): Aufgabenorientierte Visualisierung eines komplexen verfahrenstechnischen Prozesses unter Verwendung dreidimensionaler Computergrafik. In: U. Arend, E. Eberleh, K. Pitschke (Eds.): Software–Ergonomie '99 – Design von Informationswelten, Berichte des German Chapter of the ACM Nr. 53. Stuttgart: B. G. Teubner, pp. 335–344

Wittenberg, C. (2001): Virtuelle Prozessvisualisierung am Beispiel eines verfahrenstechnischen Prozesses. (VDI Fortschritt–Bericht Reihe 22 Mensch–Maschine–Systeme Nr. 5) Düsseldorf: VDI–Verlag

## Sign Language Recognition at LTI

*Karl-Friedrich Kraiss*

### Abstract

Sign languages are visual languages. They are natural languages which are used by many deaf people all over the world, e.g., GSL (German Sign Language) or ASL (American Sign Language). They may be characterized by manual (hand shape, hand orientation, location, motion) and non-manual (trunk, head, gaze, facial expression, mouth) parameters. One-handed and two-handed signs can be used.

Hearing people have difficulties to learn sign language and likewise the majority of people born deaf or who became deaf early in life, have only a limited vocabulary of the accordant spoken language of the community in which they live. Automatic sign language recognition is a rather new research area. It makes use of procedures known from speech recognition and machine vision and can provide assistive functions to deaf people.

For example, the development of a natural input device for creating sign language documents would make such documents more readable for deaf people. Also a system for translating sign language to spoken language would be of great help for deaf as well as for hearing people.

The work done in these areas is described in more detail in the following sections.

### Vision-based Sign Language Recognition

Finding and extracting information about human hands from image sequences is a complex task. Hands don't have salient texture, they can move fast and the shape can vary with 27 degrees of freedom. Nevertheless, much research is done to replace the currently still used but cumbersome data-gloves by vision based approaches in order to enable operation in arbitrary environments.

Existing systems for sign language recognition can be distinguished by the applied image acquisition and processing technique. Some systems use a single camera placed in front of the signer or as a wearable solution attached to his clothing, e.g. a baseball-cap. Either the signer must wear colored gloves or a calibrated skin color model is used to obtain information about his hands. Simple geometric features are calculated, which represent the appearance of the whole hand. This kind of approach is unlikely to work in arbitrary environments and delivers only coarse information about the hand.

Alternatively a stereo pair of cameras can deliver 3D position information. The extracted trajectories of significant points are sufficient to recognize gestures with large motion. But they lack the details needed for distinguishing gestures with minor differences.

Also three orthogonal arranged cameras and rigid 3D hand and arm models for matching and extracting their pose and position are used. Because matching is computationally too complex it is performed offline. For online experiments the cameras can still be replaced by an electromagnetic tracking system.

The system developed at LTI currently applies a single camera and color coded cotton gloves, where each finger is assigned a unique color. Glove color coding simplifies image processing and feature computation. Unfortunately the system is very sensitive to environmental conditions, since it is adapted to a uniform background.

The most promising approach to ensure highest robustness is the combination of multiple image cues, like color, motion and spatial relationships.

Karl-Friedrich Kraiss
1966 – Dipl.-Ing. EE, Communications Engineering Berlin University of Technology.
1966 – Scientific Assistant, Institute for Air Guidance, Berlin University of Technology.
1967–92 – Scientific Assistant and Branch Head (1969), Forschungsinstitut für Anthropotechnik (Human Factors Research Institute FAT / FGAN) at Werthhoven, near Bonn (as a colleague of Gunnar Johannsen).
1970 – Doctorate (Dr.-Ing.), Berlin University of Technology.
1977 – Research Scientist, NASA, Ames Research Center, Moffett Field, Ca., USA.
1987 – Habilitation at Aachen University of Technology.
1988 – Recipient of Research Award “Technische Kommunikation” by SEL-Foundation. Full Professor, Computer Science (Technische Informatik, LTI), Deputy Dean and 1998–2000 Dean, Faculty for Electrical Engineering and Information Technology, Aachen University of Technology

## Requirements for Mobile Recognition System

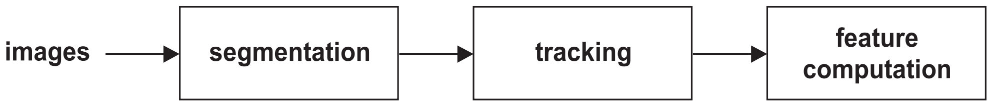
The main objective of this research effort is to enable non intrusive sign language recognition under arbitrary and unknown environmental conditions without additional aids.

*Figure 1: Example views of laboratory (right) and real environment (left). The right image represents the conditions needed for the current LTI sign language recognition system. The left image is a frame taken from the mpeg test sequence "silent".*

First of all the image background must be considered. It might be clear for a human observer, which part of a frame is the background and which the person, but this is not a trivial task for the computer. Then the relevant content must be determined, i.e. the hands and the face of the signer. Also, omitting the colored gloves means that the image processing must be made person adaptive. In addition, the color code of single fingers is lost, which makes the resolution of overlaps and occlusions more difficult.

Image processing can be divided into three steps (Figure 2). The most important step is segmentation. For extracting homogeneous connected regions several methods like watersheds, region growing, merging and splitting exist. Unfortunately they are often associated with heavy computational load and the need for initialization and parameterization.

*Figure 2: Steps of the image processing chain*



Speed up is achieved by a pre–processing step in segmentation, which amplifies relevant and eliminates irrelevant information. This kind of processing has evolved to a whole research topic known as saliency computation. We apply such a pre–processing step making use of two facts: gestures are dynamic events involving motion and are mainly performed by hands and face, which are skin colored.

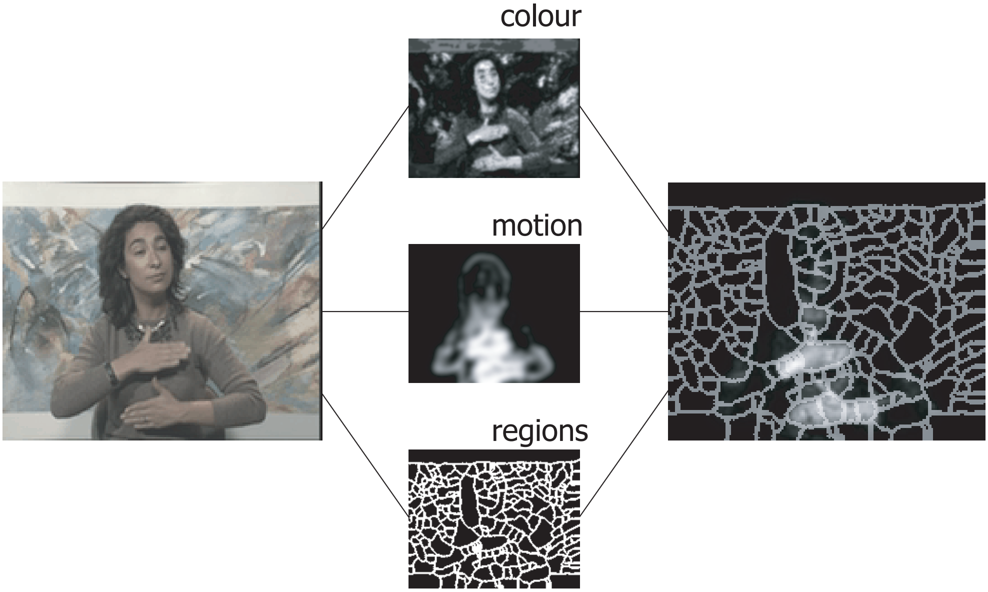



*Figure 3: Example of finding and segmenting relevant content in a video sequence for sign language recognition.*

The color model we use is an adaptation of a generic skin color model. It is based on histograms in rgb–colour space for skin and non–skin color distribution on the basis of approximately 20.000 images (2 billion pixels). These were originally collected by web–search and comprise a large variety of illumination conditions. Half of the pictures contain skin and have been segmented by hand to obtain the skin regions, the other half contains no skin. The histograms are used to calculate skin color probability for a rgb–coloured pixel by applying Bayes' theorem, which transforms an image into a probability map. The color itself is not sufficient for robust detection of relevant content, since background objects can contain similar colors. It is however possible to increase reliability of the color model by adapting the histogram to the user. Thereby the histograms can be refined to suit the individual skin color of the current user.

Extraction of motion can be achieved in different ways. Optical flow methods are accurate for estimating the direction and magnitude of motion, but are associated with too much computational load. Another method is the computation of affine transformation matrices for mapping a region to its corresponding counterpart in the subsequent image.

Unfortunately this requires knowledge of region boundaries in advance. Thus, if merely the motion magnitude is searched for, it is appropriate to use the simplified method of temporal templates. Temporal templates can be computed very fast, since they are simply the overlaid decaying difference images of two subsequent frames. We additionally blur the temporal template with a gaussian filter, to reduce the undesirable sharp steps at the borders of moving objects.

Region extraction is done with the so called watersheds, applied to the image of gradient magnitude. The gradient image detects parts of the boundaries of equally colored regions, yet these aren't closed. Watersheds consider the dark pixels as basins and the light pixels as barrage and start to fill up the gradient image with a liquid. The result is a map, where each pixel is assigned to a connected region.

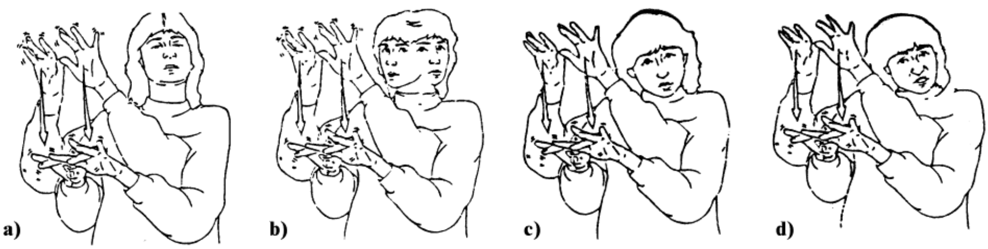
Figure 3 contains an example of the resulting image, after combining color, motion and region cues. It shows how we can effectively focus the search space to relevant content.

## Mimic in Sign Language Recognition

Until now in sign language recognition attention has always been focused on manual parameters. Vision based approaches offer a yet unexploited opportunity for the simultaneous analysis of human mimic.

It is well known that mimic plays an important role in sign language. Mimic is not only used for expressing emotions, but is utilized for encoding additional information, which can be crucial for the meaning of a signed sentence. Mimic is, e.g. applied to forward the following linguistic elements. Examples are non–manually expressible adjectives and adverbs (close / distant, intensive, … ), certain sentence types (negation, affirmation, questions, … ), direct and indirect speech, and intensification / differentiation by lip motion.

*Figure 4: Diferent meanings of a sign by varying the mimic performance:*
*a) Yes, it's snowing. b) No, it's not snowing. c) Is it snowing? d) Is it really snowing?*



Accordingly, the analysis of the signers mimic is a prerequisite for identifying certain signs and overall performance of current sign language recognition systems could benefit from redundant information.

Projects dealing with the analysis of human faces or parts of it are manifold. For example face recognition is applied in biometric identification and verification and is based on emotion independent facial features. Analysis of lip motion is supposed to improve results of speech recognition systems. Medical fields of application are medical diagnostic aids or input interfaces for palsied people.

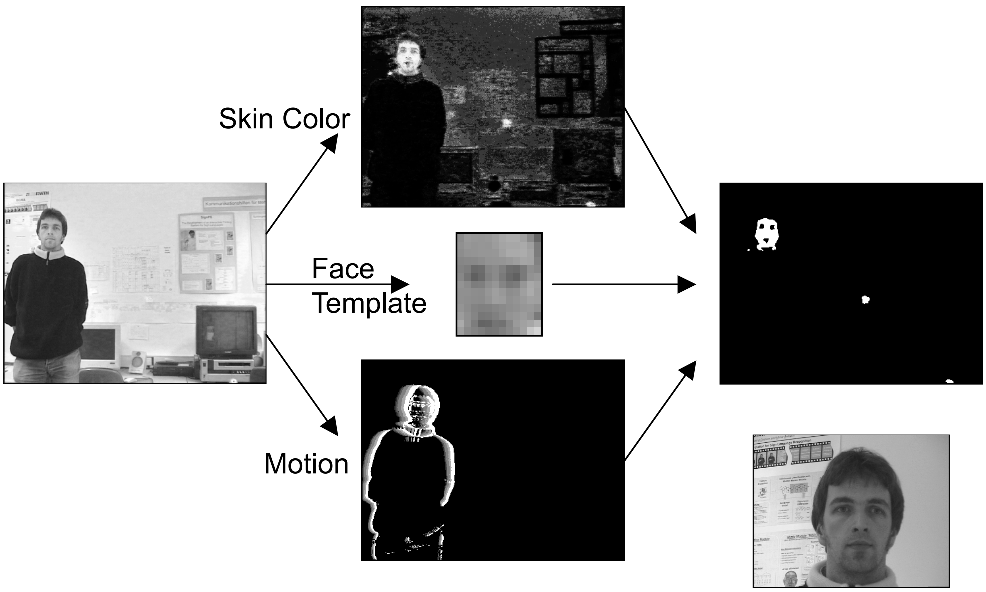
LTI is currently working on recognizing mimic expression by quantifying "action units" as defined in the Facial Action Coding System (FACS). Some examples for action units are motion of eyebrows / eyelids, aperture and shape of mouth, density of mouth and cheek wrinkles.

Subsequently technical details of automated human mimic analysis are presented. The concept consists of four modules, which are working independently of each other. This allows to parallel them by pipelining.

## Face Detection

Face detection must be performed at start-up, when the face position in a video frame is unknown. This can occur if the user enters or leaves the observed area or when face and hands overlap, so that the located face position is inaccurate.

*Figure 5: Processing scheme of face detection and scene clipping*



First the static part of the picture is masked by Temporal Templates and faded out for further handling. On the remaining Areas Of Interests (AOI) the system applies shape– and color–oriented procedures for detecting the face.

A selective *Threshold* in the color space clusters regions, which represent a conditioned probability for the occurrence of skin colored surfaces. A *Template Matching* with a multi scaled *Average Face* correlates the remaining regions for face similarity.

Simultaneously the distance to the object is measured by analyzing the lens position of the camera. This allows to calculate the absolute dimension of the segmented objects.

By adjusting the zoom–lens, optimal scene clipping is achieved for the following processing steps. Finally parameters (e.g. the color space histograms of the skin color model) are adapted to local lighting conditions for application in the next processing cycle.

## Tracking Of Characteristic Points

If the detection result are accurate, it is sufficient to track some characteristic points on the face. Time–consuming segmentation of the whole frame is no longer needed. Characteristic points for tracking are shoulders, neck, as well as lateral and upper head borders. It is also possible to determine certain face zones like eyes, nose and mouth by using symmetry relations.

In order to define these points, a *Susan* edge detector is used, which adjusts itself with model prototypes. The nodes of this prototypes refer to an *Average Face* and must be fitted to the acquired picture.

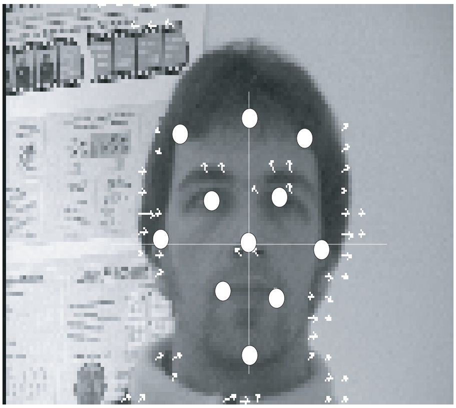


*Figure 6: Determining and tracking of characteristic points using the optical flow*

This procedure resembles the method of *Elastic Bunch Graph Matching*. Here the face is modeled as a graph, where the edges represent spatial distances to characteristic points and the nodes represent their energies derived from Gabor Wavelets.

## Extraction of Features

By prediction based on the method of *Optical Flow* and correlation of corresponding points in image sequences, key points can be traced over time and used as starting points for subsequent feature extraction.

Here a parametric model is used, which is derived from empirical data. It is based on geometric characteristics, for example the elliptical region template of eyes and mouth or the trapezoidal template of the nose respectively the nose–fold region.

Within these regions individual features are extracted by the use of Template Matching and other filter–based methods. These features are for example the line of vision, the eye's opening angle or the front formation of wrinkles. Additionally features such as size, roundness, eccentricity and further geometrical measures can be consulted.

Face analysis has the objective to classify Action Units (AU's), which are defined by anatomically derived minimal movement units of the face. For each AU three different intensity levels are distinguished, several AU's can occur simultaneously.

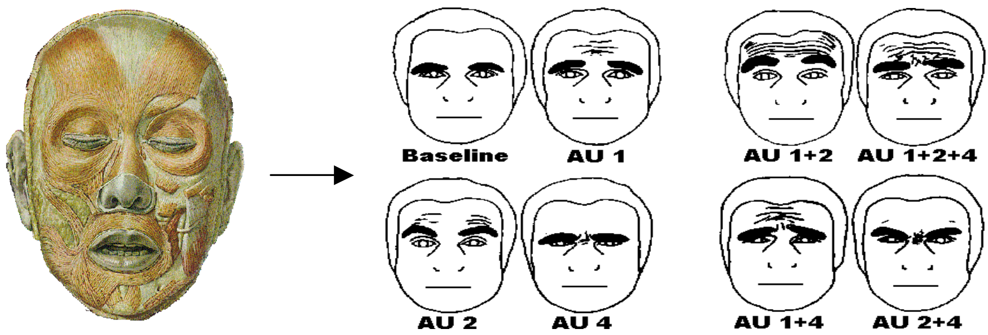



*Figure 7: Exemplary muscular based AU's and several combinations*

To achieve robust and fast performance only clearly visible mimic is evaluated. Also the number of the AU's (totally there are about 6000 different known AU combinations) is limited.

The AU's themselves are determined from the extracted features by using a *Hidden Markov* classifier. To further improve classification, several Fuzzy Sets are applied to take care of dominance, substitution and exchangeability. Also additional contextual knowledge is taken into account.

## Sign language Recognition based on Statistical Methods

The problem of sign language recognition may be characterized by the following observations: Sign varies in time and space. Even if the same person is performing the same sign twice, small changes in speed and position of the hand will occur. A sign is affected by the preceding and the subsequent sign (co–articulation). The detection of sign boundaries is not trivial.

Hidden Markov Models are suited to solve these problems of sign language recognition. The ability of HMMs to compensate time and amplitude variances of signals has been proven in the context of speech and character recognition.

A block diagram of the LTI sign language recognition system is depicted in Figure 8. At this stage the system uses a single color video camera. As described in the previous sections the feature are extracted from images regarding size, shape and position of fingers, hands and body of the signer are calculated. Only manual sign parameters are used for classification.

### Hidden Markov Modeling

Currently, each sign is modeled with one HMM. For each image a feature vector is calculated. The stream of feature vectors represents the observation sequence. The order of visited states forms the state sequence.

With Bakis topology for each HMM, the system is able to compensate variations in speed and signing. An initial state of a sign model can only be reached from the last state of a preceding model.

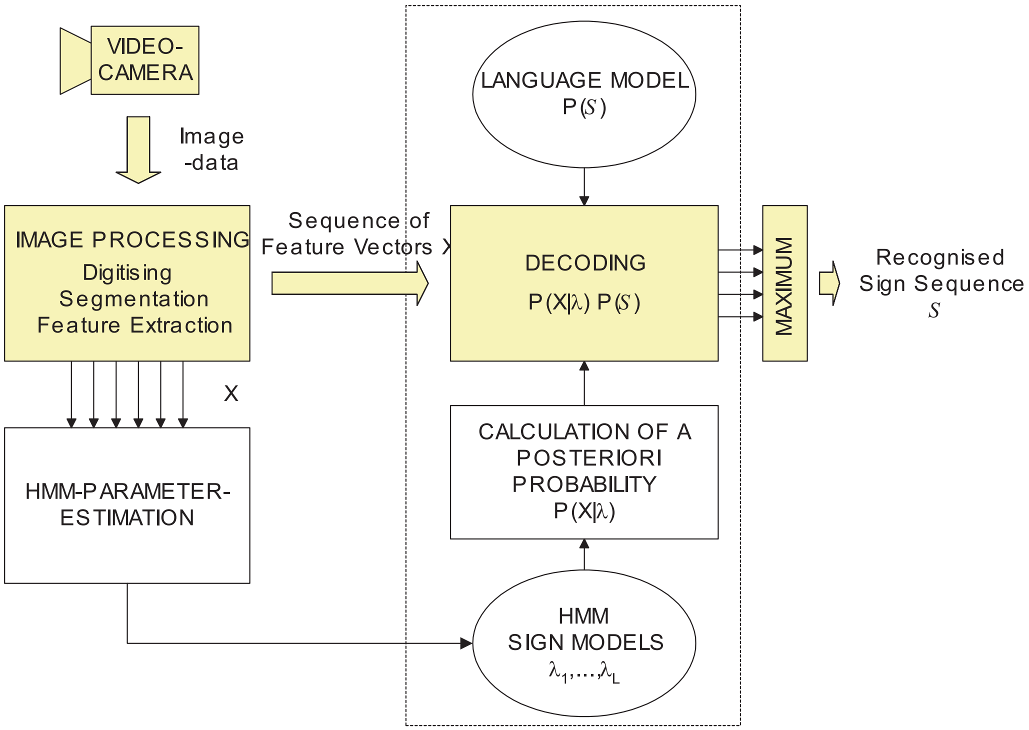
Given a specific number of observation (training) sequences, the result of the training are the HMM parameters. Since the entire sentence is trained, variations caused by preceding and subsequent signs are incorporated into model parameters. Thus in a first step model parameters are calculated for whole sentences.

After performing the training step on sentences, an assignment of feature vectors to single signs is possible and thereby the detection of sign boundaries. Now, model parameters for single signs can be calculated. These parameters are later used for the recognition procedure.

## Recognition of Continuous Sign Language

In continuous sign language recognition a sign may begin or end anywhere in the given observation sequence. As sign boundaries cannot be detected accurately, all possible beginning and end points have to be accounted for. Furthermore the number of signs within a sentence is unknown at this time. A complex search algorithm is necessary. Obviously, a brute force search is not feasible because of combinatorial explosion. Instead of searching all paths, a threshold is used to consider only a group of likely candidates. This algorithm is called beam search. Within a sign the Viterbi search is utilized.

*Figure 8: Components of the LTI continuous sign language recognition system*



## Performance of the system

The vocabulary of the sign database currently consists of 152 signs. The signs were chosen from the domain "Shopping in a supermarket". To evaluate the performance of the continuous sign language recognition system three databases are used comprising 52, 97 and 152 signs respectively. All sentences of the sign database are meaningful and grammatically well formed according to the grammar of German sign language. The sentences range from two to nine signs in length. The system is trained by one person.

*Table 1: Sign Accuracy of Person dependent Recognition*

| Test Set | Person dependent Recognition |
|---|---|
| 52 Signs | 95.4% |
| 97 Signs | 93.2% |
| 152 Signs | 91.1% |

Considering a lexicon of 52 signs the system achieves an accuracy of 95.4%, trained and tested by one person and considering all available features. For a larger vocabulary size of 152 different signs, the accuracy drops slightly to 91.1% (see Table 1). If three persons use the system recognition drops to 84.2%.

A closer look at the results shows that the system discriminates most of the minimal pairs, where the location, movement and orientation of the dominant hand are very similar. Furthermore, unseen sign transitions in the test set are often recognized. The results also indicate that the system can cope with the unconstrained order of signs within a sentence.

## Acknowledgements

Many people have contributed during the last years at LTI to the results reported in this paper. Among them are, in chronological order, Dr. Kirsti Grobel, Dr. Hermann Hienz, Britta Bauer, Suat Akyol, and Ulrich Canzler. The author is indebted to them for their successful engagement in this novel and demanding research area.

## References

Kraiss, K.-F. (Ed.) (2001) Sign Language Recognition.
In: Biannual Report Chair for Technical Computer Science, Aachen University of Technology, Shaker Verlag, ISBN 3-8265-8731-6, pp. 27-39

Grobel, K. (1999) Videobasierte Gebärdenspracherkennung mit Hidden-Markov-Modellen. Fortschritt-Berichte VDI Reihe 10, Nr. 592

Hienz, H. C. (2000) Erkennung kontinuierlicher Gebärdensprache mit Ganzwortmodellen. Shaker Verlag, Aachen

Akyol, S., B. Bauer, and U. Canzler (2000) Gesture and Mimic Interpretation for Sign Language Recognition. In: Proc. of the 4th Int. Student Conf. on Electrical Engineering, POSTER, Book of Extended Abstracts, May 25, Prag, pp. IC1

# Die Kosten von Entwicklungstätigkeiten

*Dieter Dey*

## Gedanken aus der Industrie

Nun sind mehr als 30 Arbeitsjahre vergangen. In den Jahren 1968 bis 1973 haben Gunnar Johannsen und ich sehr intensiv zusammengearbeitet, in den letzten Jahren eher zu wenig. Ich habe von ihm unter anderem intensive Anregungen zum Thema "statistische Signaltheorie" erhalten und ich hoffe, er konnte von mir auch etwas lernen. Unsere Wege trennten sich als er weiterhin die Wissenschaft pflegte und ich in die Industrie ging. Ich hatte Glück und durfte eine Reihe phantastischer Projekte durchführen.

Am Anfang meiner Industrietätigkeit gab es doch eine erhebliche Ernüchterung als ich feststellen mußte, daß unsere wissenschaftlichen Erkenntnisse meine damalige Firma eigentlich nicht interessierten. Erst vor kurzem hat Airbus Industries eine große "Human Factors Initiative" gestartet. Wir beschäftigen uns mit den "Human Factors" der Flugzeugkabine. Wir haben vor wenigen Jahren auch einen Beitrag zur generellen Spezifikation eines Cockpits geleistet, aber die Akzeptanz wurde bisher von nationalen Interessen bestimmt. Dasa Airbus hat eine Reihe von Mensch–Maschine–Untersuchungen im Zusammenhang mit der Entwicklung eines eigenen Fly–by–Wire–Systems durchgeführt und zur Zeit wird die Einkopplung elastischer Effekte der Flugzeugbewegung durch den Piloten am Simulator in Berlin untersucht.

Aber ich will nicht über einzelne Projekte oder Versuchsergebnisse berichten, sondern ein eventuell allgemein interessierendes Thema ansprechen, das mir seit einiger Zeit durch den Kopf geht: <u>Die Kosten von Entwicklungstätigkeiten</u>. Ich möchte betonen, daß die geäußerten Gedanken sehr subjektiv sind und nichts mit meiner aktuellen Tätigkeit zu tun haben.

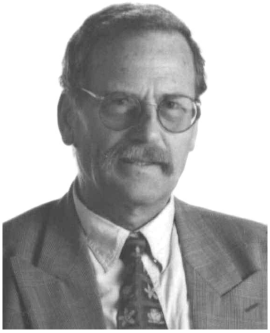
## In welchem Umfang wird Technologieentwicklung benötigt?

Mit Technologie möchte ich die industrielle Fähigkeit bezeichnen eine gewünschte Funktionalität zu realisieren. Interessant und eventuell existentiell wird eine neue Technologie für die Industrie, wenn mit ihr eine Funktionalität besser, schneller und billiger als bisher erzeugt werden kann.

Neue Technologien sind sowohl für den Herstellungsprozeß eines Produktes, für den Entwicklungsprozeß als auch für die Entwicklung neuer Produkte von Bedeutung. Es soll hier die industrielle Fähigkeit betrachtet werden, neue Technologien bei der Entwicklung von Produkten einsetzen zu können, wenn dies zur Erhaltung der Konkurrenzfähgkeit erforderlich wird. Die Überlegungen beziehen sich also im wesentlichen auf die Zeit vor der Entscheidung eine neue Technologie einzusetzen. Die Aktivitäten werden häufig als Vorentwicklung bezeichnet.

In vielen öffentlichen Äußerungen wird davon gesprochen, daß wir uns zu einer "Informationsgesellschaft" entwickeln und Informationen ein Produktionsfaktor sind. Es sind nun folgende Fakten festzustellen:

- Es existiert ein Harmonisierungsbedarf zwischen kurzfristiger Gewinnmaximierung und langfristiger Zukunftssicherung, weil die Mittel der Technologieentwicklung "einbehaltene" Gewinne darstellen.
- "Benchmarking", der Vergleich mit dem Konkurenten und daraus abgeleitet die kontinuierliche Verbesserung der eigenen Abläufe und des Produktes, ist zunächst besser geeignet die Kosten zu senken, als die Einführung technologisch völlig neuer Lösungen.
- Gewinne können durch Ablaufverbesserungen, Produktionskostensenkung und Stückzahlerhöhung relativ kurzfristig gesteigert werden.
- Es erscheint nicht sehr sinnvoll von den Abteilungen, die mit der kontinuierlichen Verbesserung und Unterstützung eines aktuellen Produktes befaßt sind, völlig neue technologische Lösungen zu erwarten.
- Für die Entwicklungsstrategie eines Unternehmens ist die Vorhersage künftiger externer Entwicklungen von großer Bedeutung. Durch kontinuierlich durchgeführte Technologieprojekte erzeugt und erhält ein Unternehmen seine Beurteilungsfähigkeit zur Nutzbarkeit aufkommender neuer Lösungsmöglichkeiten für die eigenen Produkte. Diese Arbeiten bilden den "Vorhalt" für die eigenen rechtzeitigen Entscheidungen. Diesen "Vorhalt" zu erzeugen ist eine extrem wichtige Aufgabe. Frühe Erkenntnisse sind viel Geld wert, weil für die Entwicklung eines Produktes mehrere Jahre benötigt werden und Entwicklungen unter größerem Zeitdruck die Kosten exponentiell erhöhen.



Dieter Dey, after studying aircraft guidance and air traffic at the Technical University of Berlin, started 1967 his work in the group of Rainer Bernotat. Gunnar Johannsen joint him in 1968. They worked together on aircraft control projects with preview displays and started to built up the "Anthropotechnik" group at the institut of Professor Röflger. Johannsen left Berlin in 1972 and Dey further enlarged the working group. Then he joint VFW Fokker in Bremen as a department leader for "Anthropotechnik und Simulation". He designed shiphandling and submarine simulators and was responsible for finishing the Spacelab Simulator for testing computer software. After VFW became part of MBB 1982 Dey organized and lead the theoretical oriented departments Operations Research and Navigation, SW–Engineering, System Modelling, Vehicle Control and Test Equipment of the new "Unternehmensbereich Marinetechnik and Sondertechnik". In 1986 he became project leader of the "Low Altitude Terrain Referenced Navigation" System. From 1988 he organized and lead the Main Department "Predevelopment Structures and Systems", at Deutsche Airbus GmbH in Hamburg, engaged in several technology projects like a 100-Seater Aircraft predevelopement, studies for the A380/A400M, Carbon Fiber Wing, Passenger Systems, Flight Control System and Modular Avionics. After restructuring of DASA Airbus GmbH in 1995 he worked as a project leader in a research orientated Cockpit Project and planned a High Lift System project. Today he is engaged in Human Factors activities of Airbus and works in a European Project for future Air Traffic Management.

Ein Merksatz könnte lauten: Frühzeitig das richtige tun ist äußerst kostengünstig. Es stellt sich natürlich sofort die Frage, mit welchem Budget und wie vielen Mitarbeitern wird dieser Vorhalt erzeugt. Zur Erkennung von Trends, neuen Kundenbedürfnissen und neuen technischen Möglichkeiten sind nur wenige Mitarbeiter erforderlich.

Normalerweise werden in einem Unternehmen mehrere Entwicklungsprojekte parallel abgewickelt. Da gibt es Projekte zur Modifikation von Serienprodukten, Projekte für neue Serienprodukte, Projekte für zukünftige Produkte und Projekte zur Technologieentwicklung.

Diese Projekte haben unterschiedliche zeitliche Termine. Durch Kombination von kurzfristigen Projektarbeiten und längerfristigen Technologiearbeiten, die als Hintergrundarbeiten bezeichnet werden können, läßt sich die Aufgabe kostengünstig bewältigen.

Hat ein Mitarbeiter oder eine Gruppe zwei Aufgaben mit unterschiedlichem Zeithorizont, so kann sich eine Selbstregulierung einstellen. Die Erfolge dabei können zur persönlichen Beurteilung eines Mitarbeiters herangezogen werden. Kapazitätsengpässe bei bestimmten Arbeiten machen sich zunächst an weniger kritischen, langfristig angelegten Arbeiten bemerkbar. Dies ist ein hervorragender Frühindikator für fehlende Mitarbeiter mit bestimmten Kenntnissen und der erforderlichen Motivation.

Wichtig sind eine kontinuierliche schriftliche Fixierung der Vorhersagen und eine kontinuierliche Überprüfung. Die Erkenntnisse müssen im Unternehmen periodisch kommuniziert werden.

Es sollte ein Budget für extern zu vergebende Studien und Analysen verfügbar sein. Damit kann Wissen ins Haus geholt werden und Lösungsmöglichkeiten für eigene Kapazitätsengpässe vorbereitet werden.

Wichtig ist mir die Erkenntnis, daß ein Kapazitätsproblem in der Entwicklung nicht in erster Linie eine Frage der Kopfzahl sondern eine Frage der Kenntnisse der Mitarbeiter ist, wobei ich die Fähigkeit effektive Vorgehensweisen und Tools zu nutzen mit einschließe.

## Wie sollten Entwicklungsarbeiten organisiert werden?

Die Aufteilung in Projektorganisationen und Fachbereiche hat sich durchgesetzt, aber die Auseinandersetzungen bezüglich Zuordnung von Mitarbeitern, Größe von Organisationen, Abläufe und Kompetenzen sind hoch aktuell.

Die deutliche Akzeptanz, daß zu einem erfolgreichen Projekt sowohl gute Organisatoren (Projektleiter) als auch gute Fachleute gehören, läßt oft zu wünschen übrig, weil es die eigene Argumentation der einen oder anderen Seite stört.

Unterlegt sind diese Diskussionen von Problemen der Reputation und Bezahlung. Bei der Argumentation, ein Projektleiter muß besser bezahlt werden, weil er die Verantwortung trägt, wird übersehen, daß seine Erfolge ganz wesentlich von der Qualifikation und Motivation der für ihn arbeitenden Mitarbeiter und Organisationseinheiten abhängt. Wobei als Qualität eines Projektleiters nicht seine Fähigkeit zur Druckerzeugung und Selbstdarstellung bezeichnet wird, sondern seine Fähigkeit, die Erzeugung der erforderlichen Ergebnisse in Zeit, Qualität und Kosten zu organisieren.

Es ist bekannt, daß eine Gruppe guter Fachleute noch kein Garant für eine optimale Projektabwicklung ist. Aber was bringt ein guter Projektleiter ohne gute und motivierte Fachleute zustande?

Für den Erfolg eines Entwicklungsprojektes sind gute Organisatoren und gute Fachleute mit gegenseitigem Respekt erforderlich. Eine wesentliche Aufgabe der Organisatoren ist die Synchronisation paralleler Aktivitäten. Die Hauptaufgabe der Fachleute ist die engagierte Erzeugung zielgerichteter, konkurrenzfähiger, qualitativ hochwertiger Arbeitsergebnisse. Dabei treten für den Projektleiter immer wieder Prioritätsentscheidungen auf. Für eine erfolgreiche Projektdurchführung in Termin und Kosten sind vorausschauend wirksame Entscheidungen erforderlich, wozu Fachkenntnisse und Erfahrungen benötigt werden. Projektleiter, die neben ihren organisatorischen Fähigkeiten diese Zusatzqualifikationen aufweisen, sind gesucht und ihr Geld wert. Wobei nicht vergessen werden sollte, daß die Firmenkultur ein positives Umfeld für die Organisation und Erarbeitung von Ergebnissen bilden muß.

## Wie können Entwicklungskosten gesenkt werden?

Das Problem Entwicklungskosten ist heute deswegen aktueller geworden, weil es darum geht, Entwicklungszeiten und Entwicklungskosten zu reduzieren. Zu einem optimalen Entwicklungsablauf gehören die Einhaltung von Terminen, Qualität und Kosten. Ein solcher Ablauf ist zu organisieren. Normalerweise bewirken zu knappe Vorgaben am Ende Kostenerhöhungen im Projekt, weil die erforderlichen Ziele nicht erreicht wurden.

Der kritischste Punkt einer Entwicklungsarbeit ist dabei die Einhaltung von Qualität, denn während Termine abgelesen und Kosten addiert werden können, ist die Qualität von Entwicklungsleistung sehr viel schwieriger zu beurteilen. Während die Qualität von Fertigungsprodukten sofort nachgemessen werden kann, ist die Bestimmung der aktuellen Qualität einer Entwicklungsarbeit sehr aufwendig und erfordert erhebliche Kenntnisse und Erfahrung. Qualitätsmängel zeigen sich oft erst in späteren Projektphasen.

Es gibt einen Zusammenhang zwischen der Beeinflussbarkeit von Produktkosten im Lebenszyklus und den Projektphasen (siehe Bild 1). Diese Darstellung ist als eine Modell vorstellung zu sehen. Das Konzept für ein neues Flugzeugmuster basiert natürlich auf den Ergebnissen der vorher durchgeführten Technologieprojekte. Die Konzept–Formulierung kann auch als "Vorentwicklung" bezeichnet werden. Wichtig ist die Vorstellung, daß über zwei Drittel der Lebenszykluskosten durch das Konzept explizit oder implizit festgelegt werden und daher die Beurteilungsfähigkeit und Beherrschung neuer Technologien zwar direkt in die Entwicklungskosten eingehen, sich aber während des gesamten Lebenszyklus auswirken.

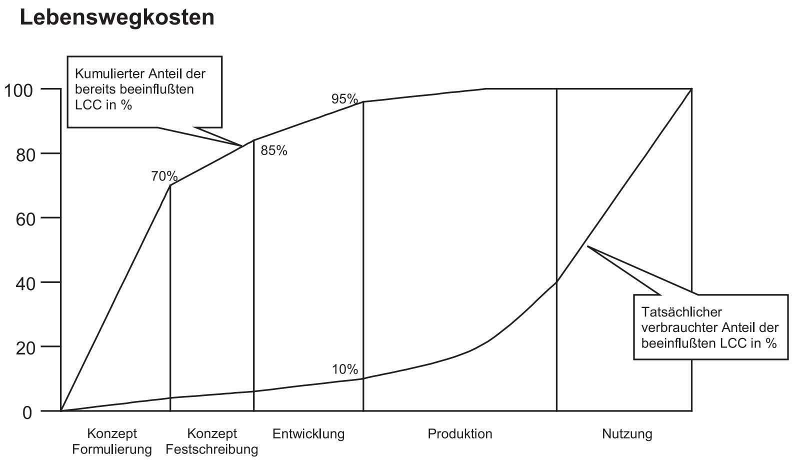



*Bild 1: Beeinflußbarkeit von Produktkosten im Lebenszyklus*

Die Entwicklungskosten werden in dem dargestellten Prinzipbild mit 10 % der Lebenszykluskosten angegeben. Dieser Wert wird um so kleiner, je längere Nutzungsphasen betrachtet werden. Es sollte daher nicht der Schluß gezogen werden, daß ihre Höhe unwichtig ist. Entwicklungskosten sind vom Unternehmen vorzufinanzieren und belasten die aktuelle Ertragskraft. Erst mit dem Verkauf fertiger Produkte nimmt die finanzielle Belastung des Unternehmens ab, wenn ein genügend hoher Preis für das Produkt erzielt werden kann.

Wenn getroffene Festlegungen im Projektverlauf geändert werden, entstehen umso höhere Kosten:

- je mehr Folgeentscheidung und Festlegungen betroffen sind,
- je mehr Mitarbeiter diese Änderung berücksichtigen müssen,
- je weiter der Produktionsprozeß fortgeschritten ist.

Ein Punkt ständiger Diskussion ist die Beurteilung eines Entwurfes und der damit erforderlichen Arbeiten hinsichtlich der Erfüllung der zu Beginn der Entwicklung festgelegten Anforderungskriterien mit ihrer impliziten Rangfolge. Es lassen sich wesentliche Kosten durch eine Optimierung des Entwurfs hinsichtlich der erforderlichen Abdeckung der Anforderungskriterien einsparen. Dies könnte als Qualität eines Entwurfs bezeichnet werden. Unter Qualität der Entwicklungsarbeiten soll ihre Transparenz, Dokumentation, Steuerbarkeit und Fehlerfreiheit bezeichnet werden.

Es gibt eine sehr schöne Darstellung über die Kosten für die Beseitigung von Fehlern als Funktion des Projektfortschrittes bei SW–Projekten (siehe Bild 2). Dieser exponentielle Zusammenhang über Kosten von Fehlern und der Projektphase ihrer Entdeckung und Beseitigung gilt allgemein für Entwicklungsprojekte, wobei man sich über den Exponentialfaktor streiten kann. Die Kosten werden aber meistens nicht im %–Bereich sondern um Faktoren beeinflußt.

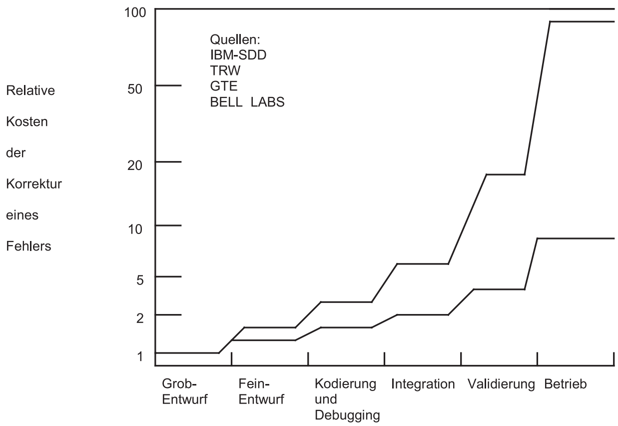



*Bild 2: Korrekturkosten in Abhängigkeit vom Zeitpunkt des Auffindens eines Fehlers (Quelle Boehm)*

Aus den vorangegangenen Beobachtungen folgt, daß frühzeitig im Projekt getroffene tragfähige ("richtige") Entscheidungen ein enormes Kostensenkungspotential bewirken.

## Wie beeinflußt die Größe eines Projektes seine Kosten?

Für den Zusammenhang zwischen dem Umfang der Arbeiten (der Größe des Projektes) und seinen Kosten dient wieder eine Modellvorstellung aus der SW–Entwicklung, die sich auf kreative Entwicklungsprojekte (Technologieentwicklung) gut anwenden läßt (siehe Bild 3). Der Aufwand steigt exponentiell mit der Größe des Projektes. Dies ist die Begründung für die Strukturierung (Modularisierung) eines Projektes in überschaubare Einheiten. Strukturierung dient der Transparenz und Steuerbarkeit und der Ermöglichung der Gleichzeitigkeit von Arbeiten und eines erhöhten Mitarbeitereinsatzes und damit auch der Ermöglichung der Entwicklungszeitverkürzung. Eine wirksame Strukturierung hat einen großen Einfluß auf den Projekterfolg. Sie kann nach verschiedensten Gesichtspunkten, wie z. B. nach Funktionen, nach Baugruppen, nach Organisationen, nach zeitlichen oder auch politischen Prioritäten vorgenommen werden.

Einem Projektleiter sollte klar sein, daß die Vergabe von Arbeiten besonders bei Technologieprojekten auch der Organisationsentwicklung und dem Training bzw. der Know–How–Entwicklung der Mitarbeiter dienen. Durch eine gezielte Vergabe von Aufträgen oder auch Nichtvergabe werden Organisationen gestärkt oder geschwächt, also Organisationsentwicklung betrieben.

Durch eine geschickte Modularisierung der erforderlichen Arbeiten und der anschließenden Bündelung einzelner Arbeitspakete werden die späteren Projektkosten schon zu Beginn eines Projektes sehr stark beeinflußt.

Ein weiterer Kosteneinfluß besteht durch die realistische Abschätzung des Arbeitsumfanges und der daraus abgeleiteten erforderlichen Zahl der Mitarbeiter. Zu spätes Einphasen von Mitarbeitern erhöht die Kosten.

Es erscheint mir als ein verbreiteter Irrglaube, daß durch besonders knappe Mengenvorgaben für einzelne Aufgaben die Projektkosten niedrig gehalten werden. Meiner Meinung nach werden die Kosten durch eine gute Strukturierung, die ausreichenden Ressourcen und die intensive Kommunikation und Koordination bestimmt.

## Wie beeinflussen Terminverschiebungen die Entwicklungskosten?

Die Fähigkeit zur Abschätzung des Zusammenhangs zwischen Kosten und Terminverschiebungen liegt im Erfahrungsbereich. Ein Entwicklungsergebnis (ein "Bau") läßt sich mit wenigen Mitarbeitern und längerer Zeit häufig günstiger erstellen als mit vielen Mitarbeitern in sehr kurzer Zeit. Beim Einsatz vieler Mitarbeiter treten organisatorische Verluste und erhebliche Kommunikationsverluste auf. Die Qualität der internen Kommunikation beeinflußt den Exponentialfaktor der Kostenkurve.

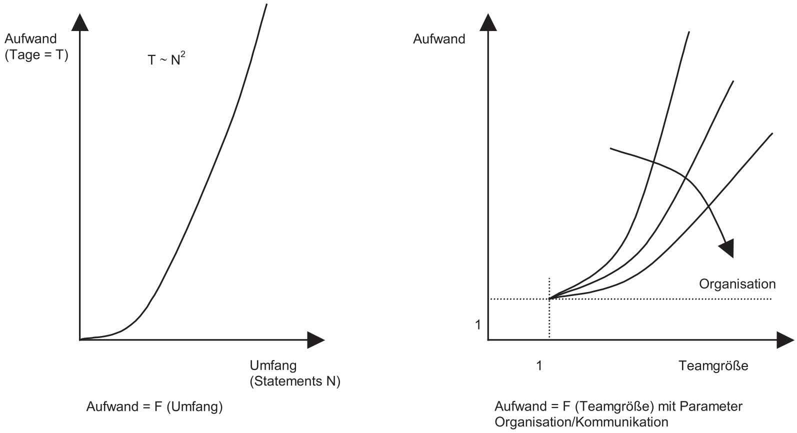



*Bild 3: Arbeitsaufwand und Abhängigkeit*

Bei komplexen Entwicklungsprojekten, Projekte in die verschiedenen Fachabteilungen eingebunden sind, sind die Aktivitäten (Arbeitspakete) aufeinander abgestimmt. Verschiebungen an einer Stelle verursachen Folgeverschiebungen an anderen Stellen mit insgesamt exponentiellen Kostenerhöhungen. Der erste Ansatz des Projektleiters ist daher, die Forderung nach Einhaltung von Terminen. Um dies lokal zu erreichen, sind normalerweise mehr Mitarbeiter erforderlich. Was aber, wenn keine zusätzlichen Mitarbeiter verfügbar sind?

Die Auswirkungen des Abziehens von "Bauarbeitern" von einer "Baustelle", um damit an anderer Stelle einen Bedarf zu decken, gehört zu unserem Erfahrungsschatz. Dies führt häufig zu Kostenproblemen im betrachteten Projekt. Hier die richtigen Prioritätsentscheidungen zu treffen ist die Aufgabe des Vorgesetzten von Fachbereichen und Projektleitern, häufig der Entwicklungschef und oft auch die Geschäftsführung.

Nun kann man ja sagen, die Umorganisation von Arbeitspaketen gehöre zum industriellen Alltag. Das Problem liegt in der Eingrenzung von "Brandherden", um nicht die Leistungsfähigkeit des Unternehmens zu verringern, weil die Umorganisation von Arbeitspaketen häufig schwer zu übersehende Kosten und Risikoverschiebungen an verschiedensten Stellen des Unternehmens zur Folge haben können.

Wünschenswert ist die “Bekämpfung” und Beseitigung von Terminverschiebungen durch den verursachenden Fachbereich selbst. Hierzu muß er in die Lage versetzt werden.

Eine Möglichkeit zur Einarbeitung neuer Mitarbeiter und zur Schaffung einer “Einsatzreserve” besteht in der Durchführung terminunkritischer, langfristiger angesetzter Hintergrundprojekte.

Eine zweite Möglichkeit besteht in der Sicherstellung der erforderlichen Kapazitäten und Fähigkeiten durch die Vergabe von Aufgaben durch den Fachbereich. Manchmal ist sogar eine Vergabe innerhalb des Unternehmens möglich, zum Beispiel bei lokalen Auslastungslücken oder erforderlichen Organisationsanpassungen.

In diesen Zusammenhang paßt die Erkenntnis, daß Verspätungen im Projekt durch den Einsatz zusätzlicher Mitarbeiter häufig zu weiteren Terminverschiebungen führen, weil auch bei vorliegender guter Dokumentation die Einarbeitung Zeit benötigt.

## Welchen Einfluß hat die Qualität von Mitarbeitern auf die Kosten?

Die Qualität von Entwicklungsarbeiten (Fehlerfreiheit) hängen von der Qualifikation und Motivation der Mitarbeiter und vom Informationsfluß in den Fachabteilungen ab. Die Fehlerfreiheit von Arbeiten hängt natürlich auch von den Kenntnissen der beauftragten Mitarbeiter ab. Durch interdisziplinäre Teams kann dafür gesorgt werden, daß alle Aspekte einer Aufgabenstellung im Ergebnis berücksichtigt werden.

Beim Einsatz von Teams ist besonders darauf zu achten, daß die aus den Projektzielen abgeleiteten Aufgabenziele klar erkenntlich sind und bleiben, da sonst gerade Teamergebnisse sehr ineffektiv sein können.

Ein Element des Informationsflusses ist die Qualität der griffbereiten (“on–line”) verfügbaren Dokumentation. Im Verlauf eines Projektes entstehen projektspezifische Informationen, deren Kenntnisse für jeden neu einzusetzenden Mitarbeiter erforderlich sind.

Der Informationsfluß in einer Fachabteilung oder einem Projekt wird behindert, wenn Mitarbeiter der Meinung sind, sie müßten sich unabkömmlich machen, weil sonst ihre Arbeitsleistung nicht erkannt und auch finanziell gewürdigt wird. Hier lauert eine Falle für Vorgesetzte und Projektleiter, wenn sie nicht unterscheiden zwischen dem Berichtenden und dem fähigen Erzeuger von Arbeitsergebnissen. Arbeitsatmosphäre und Firmenkultur gehen hier indirekt in die Projektkosten ein.

Sollten Entwicklungs–Mitarbeiter mit bestimmten Kenntnissen fehlen, so können sie nicht kurzfristig “aus dem Boden gestampft” werden. Neue Mitarbeiter einzustellen und einzuarbeiten kostet Zeit und Geld (Kontierung). Die erforderliche Zeit läßt sich häufig auch nicht durch viel Geld ersetzen. Gute Erfahrungen habe ich bei der arbeitsmäßigen Kopplung erfahrener (älterer) Mitarbeiter mit Neulingen machen können.

Es gibt Mitarbeiter unterschiedlicher Leistungsfähigkeit. Ein Vorgesetzter sollte wissen, von welchem Mitarbeiter er ein gewünschtes Arbeitsergebnis in einem Monat, von welchen in 3 Monaten und von welchen wahrscheinlich überhaupt nicht erhält. Daraus folgt, daß die Kosten eines Projektes durch die Zuordnung von bestimmten Mitarbeitern erheblich beeinflußt werden. Dieser Effekt wird noch verstärkt, wenn die Kostensätze jedes einzelnen Mitarbeiters einer Fachabteilung oder eines Bereiches gleich hoch sind.

Ein schwieriges Thema ist der Einfluß der Motivation einzelner Mitarbeiter auf die Projektkosten. Dienst nach Vorschrift und innere Kündigung können erhebliche Kostenfaktoren bei Entwicklungsarbeiten darstellen.

## Wie pflege ich die Leistungsfähigkeit von Mitarbeitern?

Entwicklungs–Mitarbeiter können nicht immer Höchstleistungen – eventuell auch verbunden mit Überstunden – erbringen. Phasen außergewöhnlicher Anspannung müssen sich mit "Auftank"–Phasen abwechseln.

Hochqualifizierte Mitarbeiter sollten nicht aus finanziellen Gründen in eine Projektleitertätigkeit (organisatorische Tätigkeit) drängen, wenn ihnen diese Tätigkeit gar nicht liegt. Gerade unter Ingenieuren finden sich viele fachlich zu begeisternde Mitarbeiter. Werden diese Mitarbeiter langfristig als reine Spezialisten ("Indianer") abgestempelt, bleiben ihre Leistungen häufig hinter ihrem möglichen persönlichen Niveau zurück. Viele Firmen haben aus diesem Grund Fachlaufbahnen geplant, diese haben sich aber bisher nicht sonderlich durchgesetzt.

Ein anderes Extrem ist der kommunikationsfreudige vielleicht sogar fachfremde Mitarbeiter, der als Projektleiter und Organisator eingesetzt wird und keine fachlichen Kenntnisse und Erfahrungen besitzt, sondern nur die Hierarchie kennt. Für solche Mitarbeiter bietet die Matrixorganisation genügend "Beweise", um bei Mißerfolgen (Nichteinhaltung von Terminen, Leistungen, Kosten) nicht bei sich suchen zu müssen.

Entwicklungs–Mitarbeiter benötigen ein ständiges Training und eine Weiterentwicklung ihrer Kenntnisse und Fähigkeiten. Sie fühlen sich häufig bei herausfordernden Aufgaben wohl, die mit einem gewissen Prozentsatz (10 – 20 %) über ihre bisherigen Tätigkeiten und Kenntnisse hinaus gehen.

Die verschiedenen Anforderungen an die Mitarbeiter einer Abteilung oder eines Bereiches wie

- Einarbeitung und Erneuerung von Kenntnissen,
- Anpassungs– und Auftankphasen und
- Anpassung der Kapazitäten in den verschiedenen fachlichen Wissensgebieten

können durch die Kombination von jüngeren und älteren Mitarbeitern, von kurzfristiger Projektarbeit und längerfristigeren Technologieprojekten verbunden mit externen Kooperationen erreicht werden.

## Wie wirkt sich der Einsatz von "Tools" auf die Kosten aus?

Heute lassen sich viele Tätigkeiten nicht mehr ohne Rechnerunterstützung und sogenannte "Tools" durchführen. Ein Paradoxon ist, daß je leistungsfähiger ein Tool ist, desto mehr a–priori–Kenntnisse (d. h. Einarbeitungszeit) werden benötigt. Bei der Toolbeschaffung sind nicht nur die Beschaffungskosten, sondern auch die Ausbildungskosten und die erforderliche kontinuierliche Auslastung zu beachten.

"Tools" dienen der Automatisierung von Arbeiten, der Aufwand für ihre Erstanwendung ist relativ hoch, Modifikationen lassen sich anschließend leichter durchführen. "Tools" stellen häufig eine erhebliche Investition in die Leistungsfähigkeit einer Abteilung dar. Soll ihre Erstanwendung oder gar ihre Weiterentwicklung aus Projektkosten bezahlt werden, so sind Kosten– und Terminplanungen mit großen Unsicherheiten behaftet. Auch bei Nichteinhaltung geplanter Vorgaben kann am Ende eines Projektes ein einmal eingeschlagener Weg nur schwer geändert werden, dabei können extreme Zugzwänge und Kosten auftreten.

Die Effektivität von "Tools" wird beeinflußt durch die Weiterverwendung der Arbeitsergebnisse, d. h. den Schnittstellen zu den vorgelagerten und nachgelagerten "Tools".

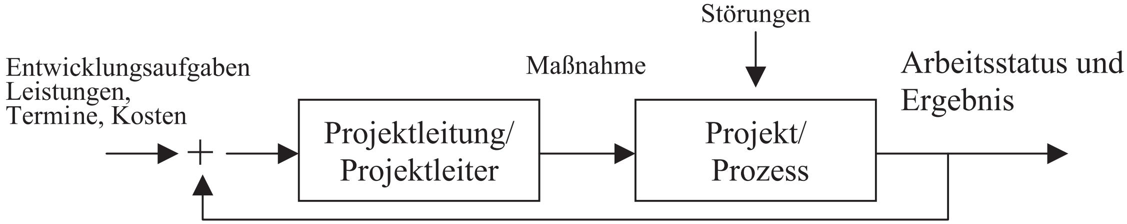
"Tools" können sehr schnell sehr umfangreiche Ergebnisse liefern. Dies kann bei falschen Eingangsdaten sehr schnell zu sehr viel Unsinn führen. Der Einsatz von Tools in größeren Projekten, die nicht in Pilot–Projekten vorher ausprobiert wurden, kann geradezu als gefährlich für einen Projekterfolg eingestuft werden.

Die Wirkung des Einsatzes von Tools auf die Projektkosten macht die Notwendigkeit einer vorausschauenden strategischen Planung und Technologieentwicklung besonders deutlich.

## Kann man kosteneffektive Entwicklungsprojekte organisieren?

Die Durchführung eines Projektes kann als ein Regelkreis dargestellt werden. Eingangsgrößen (Eingangsvektor) sind die inhaltlichen, terminlichen und kostenmäßigen Anforderungen der Entwicklungsaufgabe. Die Projektleitung fungiert als Regler, sie beeinflußt durch Maßnahmen Abweichungen des Entwicklungsprozesses vom geplanten Verlauf.

*Bild 4: Modellvorstellung für eine Projektdurchführung.*



Die Problematik der kosteneffektiven Organisation von Entwicklungsprojekten wird heute verschärft durch die Forderung, die Entwicklungszeit zu verringern und die Kosten zu senken bei gleichbleibender oder sogar verbesserter Qualität.

Als Regelungstechniker kann man sich diese Forderungen als eine Erhöhung des Verstärkungsfaktors vorstellen mit der Gefahr der Instabilität des Prozesses.

Projektstrukturpläne und Netzpläne sind bekannt. Sie dienen der inhaltlichen und zeitlichen Strukturierung der Projektdurchführung bzw. des Entwicklungsprozesses.

Meine These lautet:

*Die Verbesserung des Übertragungsverhaltens (der Regelbarkeit) des Prozesses und damit der Projekterfolg erfolgt durch die Sicherstellung der erforderlichen fachlichen Beiträge in Qualität, Termin und Kosten.*

*Der Verstärkungsfaktor des gesamten Regelkreises und damit die Verbesserung seines Übertragungsverhaltens kann durch eine Vorhaltbildung der Projektleitung (differenzierendes Verhalten) erhöht werden ohne in Stabilitätsprobleme zu geraten.*

Hier schließt sich der Kreis meiner Betrachtungen:

- Auch Projektleitungstätigkeiten lassen sich inhaltlich qualitativ bewerten und haben damit auch eine fachliche Komponente. Ihre Fähigkeit zur Vorhaltbildung kann als Fähigkeit zur frühzeitigen Erkennung von Abweichungstendenzen bezeichnet werden.
- Projektleitungen sollten ein Interesse an gut funktionierenden Fachabteilungen haben. Hierzu ist häufig die "Unterstützung" der nächsthöheren Organisationsebene erforderlich.
- Durch kontinuierliche Beauftragung und Förderung einer Fachabteilung steigt ihre Qualität.

Zusammenfassend läßt sich sagen: Abteilungsleiter / Fachbereichsleiter mit fachlich leistungsfähigen Organisationen bilden zusammen mit qualitativ hochwertigen Projektleitungen die Grundlage für kostengünstige (erfolgreiche) Projekte, wobei bei allen dynamischen Vorgängen das frühzeitige Erkennen von Abweichungen (die Vorhaltbildung) die Grundlage für Kostenoptimierungen bildet.

Zur Erkennung von Abweichungen ist eine qualitativ hochwertige Arbeitsplanung und eine kontinuierliche Überprüfung der Arbeitsergebnisse erforderlich.

## The Contributors

Ass. Prof. Dr. Eng. Salaheddin Ali

Department of Computer Science

Al-Quds University, Jerusalem

S.Ali@gmx.de

Professor Dr. James L. Alty

Dept. of Computer Science

University of Loughborough

Loughborough, Leicestershire, UK

Dr.-Ing. Sabine Borndorff-Eccarius

T-Systems GEI GmbH, Mülheim / Ruhr, Germany

Sabine.Borndorff-Eccarius@t-systems.com

Dr.-Ing. Bernd-Burkhard Borys

IMAT Systems Engineering and Human-Machine Systems

University of Kassel, 34109 Kassel, Germany

B.Borys@.uni-kassel.de

Dr. Guy Boy

Director, European Institute of Cognitive Sciences and Engineering (EURISCO),

Toulouse, France

Dr. Pietro Carlo Cacciabue

Commission of the European Communities

Joint Research Centre

Institute for the Protection and Security of the Citizen

Human Factors Center

21020 Ispra (Va), Italy

pietro.cacciabue@jrc.it

Dr.-Ing. Dieter Dey

DaimlerChrysler Aerospace Airbus, Bremen, Germany

Professor Dr. Horst-Peter Hesse

Mozarteum, Alpenstr. 48, 5020 Salzburg, Austria

Dr.-Ing. Martin Hollender

Bruchhäuser Weg 12, 69124 Heidelberg, Germany

Professor Dr.-Ing. Wolfgang Holzapfel
Director, Institute of Measurement and Automation
University of Kassel, 34109 Kassel, Germany
Professor Dr. Toshiyuki Inagaki
Institute of Information Sciences and Electronics
University of Tsukuba, Tsukuba 305-8573, Japan
Dr. Kensuke KAWAI
TC Chair, IFAC Human-Machine Systems
Editor, IFAC Control Engineering Practice
Toshiba Corporation
Principal Office, Power Plant Division
4-36-5, Tsurumi-Chuo, Tsurumi-ku
Yokohama-shi, 230-0051, Japan
Professor Dr.-Ing. Karl-Friedrich Kraiss
Department of Technical Computer Science (LTI)
Aachen University of Technology
Ahornstr. 55, 52074 Aachen, Germany
kraiss@techinfo.rwth-aachen.de
Professor Dr.-Ing. Anton Matzenmiller
Dean, Department of Mechanical Engineering
University of Kassel, 34109 Kassel, Germany
Professor Dr. Neville Moray
Magagnosc, 06520, France
Professor Dr. Reiner Onken
Universität der Bundeswehr München
Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany
reiner.onken@unibw-muenchen.de
Dr. William B. Rouse
Enterprise Support Systems
Atlanta, Georgia, USA

Ass. Prof. dr. ir. M. M. (René) van Paassen
Delft University of Technology
Faculty of Aerospace Engineering
Kluijverweg 1, 2629 HS Delft, The Netherlands
Professor Dr. Andrew P. Sage
Department of Systems Engineering and Operations Research,
George Mason University
Fairfax, VA 22030-4444, USA
Professor Dr. Thomas B. Sheridan
Massachusetts Institute of Technology
Cambridge, MA 02139, USA
Ass. Prof. Dr. Eng. Yu Shibuya
Kyoto Institute of Technology
Matsugasaki, Sakyo-ku, Kyoto-city
Kyoto 606-8585, Japan
shibuya@dj.kit.ac.jp
Professor dr. ir. Henk G. Stassen
Delft University of Technology
Design, Engineering & Production
Structural Optimization & Computational Mechanics
Mekelweg 2, 2628 CD Delft, The Netherlands
Dipl.-Ing. Andreas Völkel
IMAT Systems Engineering and Human-Machine Systems
University of Kassel, 34109 Kassel, Germany
Dr.-Ing. Carsten Wittenberg
Siemens AG
Corporate Technology - User Interface Design
81730 Munich, Germany
carsten.wittenberg@siemens.com

## Gunnar Johannsen

*Systems Engineering and Human-Machine Systems (IMAT-MMS),*
*University of Kassel*
*Mönchebergstr. 7, 34109 Kassel, Germany*
*Phone: +49 561 804-2658*
*G.Johannsen@.uni-kassel.de*
*www.imat.maschinenbau.uni-kassel.de/members/joh/johhome.html*

Gunnar Johannsen is University Professor of Systems Engineering and Human-Machine Systems in the Institute for Measurement and Automation (IMAT) of the Department of Mechanical Engineering and Head of the Laboratory for Human-Machine Systems at the University of Kassel, Germany, since 1982.

Gunnar Johannsen received his Dipl.-Ing. degree (1967) in Communication and Information Engineering (Department of Electrical Engineering) and the Dr.-Ing. degree (1971) in Flight Guidance and Manual Control (Department of Transport) from the Technical University of Berlin, Germany. In addition, he studied music for three years within the Sound Engineering curriculum at the University School of Music, Berlin. In 1980, he habilitated (Dr. habil.) and became Private Docent in the teaching area of Human-Machine Systems of Aeronautics and Astronautics in the Department of Mechanical Engineering at the Technical University of Aachen, Germany. From 1971 to 1982, he was division head in the Research Institute for Human Engineering (FGAN-FAT) near Bonn, Germany.

During longer research stays, he worked in the University of Illinois at Urbana-Champaign in the USA (1977–1978), in the Kyoto Institute of Technology and the Kyoto University in Japan (1995) as well as in the Technical University of Vienna, Austria (1999). The latter work was on auditory displays for human-robot communication; it was also supported by the Institute of Electro-Acoustics, Experimental and Applied Music of the University of Music and Performing Arts Vienna.

Gunnar Johannsen is author and editor of numerous publications in conference proceedings, refereed journals, and in book form, e.g., author of "Mensch-Maschine-Systeme" (<Human-Machine Systems, in German>; Berlin: Springer 1993) and editor of "Monitoring Behavior and Supervisory Control" (together with T. B. Sheridan, MIT, Cambridge, USA; Plenum Press, New York 1976). In IFAC (International Federation of Automatic Control),

he founded and chaired the Working Group on Man–Machine Systems (1981–1990). He served as Chairman of the International Program Committee for four of its Symposia on Analysis, Design, and Evaluation of Human–Machine Systems in 1982 (Baden–Baden), 1985 (Varese), 1989 (Xi'an), and September 2001 (Kassel). Also in September 2001, he created and was main responsible of an International Workshop on Human Supervision and Control in Engineering and Music, with a scientifically embedded orchestra concert.

In January 2001, he was elected to the grade of Fellow of the IEEE "for contributions to human–machine systems engineering, cognitive ergonomics, human–computer interface design, and human–centered automation".

His current research interests are in analysis, design, and evaluation of human–machine systems, human–centred design methods, cognitive systems engineering, graphical, auditory, gestural, and multimedia user interfaces, audio and music technologies, decision support systems, knowledge engineering and processing techniques (expert systems, neural networks, fuzzy logic, data mining), and co–operative work – in such application domains as vehicle and process control, telematics, and information logistics.

Over several years, Gunnar Johannsen studied orchestra conducting in Hamburg, Vienna, and Kassel. He conducted Toru Takemitsu's November Steps for orchestra with Shakuhachi and Biwa in the Workshop concert of September 2001, as well as the second movement of Beethoven's Symphony No. 2 in its interactive orchestra rehearsals.

Whenever he can find some time, he likes hiking and enjoys nature.

# Publications of Gunnar Johannsen

## From 1960 to 1971


Dey, D. und G. Johannsen: Stabilisierung und Lenkung von Fahrzeugen mit Hilfe der Voranzeige. Bericht Nr. 50, Institut für Flugführung und Luftverkehr, Technische Universität, Berlin, 1969

Johannsen, G.: Der Einfluß einer Voranzeige auf Verteilungsdichte– und Leistungsdichtefunktionen bei der manuellen Folgeregelung eines Beschleunigungssystems. Regelungstechnik Prozeß–Datenverarbeitung, 18 (1970), S. 65–69

Johannsen, G.: Entwicklung und Optimierung eines vielparametrigen nichtlinearen Modells für den Menschen als Regler in der Fahrzeugführung. Dissertation, Technische Universität, Berlin, 1971

Dey, D. und G. Johannsen: Stabilisierung und Lenkung von Fahrzeugen mit Hilfe der Voranzeige. Teil II: Übergrundanzeige und künstlicher Horizont. Bericht Nr. 61, Institut für Flugführung und Luftverkehr, Technische Universität, Berlin, 1971


## From 1972 to 1983


Johannsen, G.: A method for the development and optimization of controller––models for man–machine systems. In: R. K. Bernotat and K.–P. Gärtner (Eds.): Displays and Controls. Amsterdam: Swets & Zeitlinger, 1972, pp. 349–366

Johannsen, G.: The design of a nonlinear multi–parameter model for the human operator. In: R. K. Bernotat and K.–P. Gärtner (Eds.): Displays and Controls. Amsterdam: Swets & Zeitlinger, 1972, pp. 367–388

Johannsen, G.: Der Einsatz von Voranzeigen bei der manuellen Kurs– und Lageregelung von VTOL–Flugzeugen.
In: Deutsche Luft– und Raumfahrt Mitt. 72–04 (1972), S. 23–33

Johannsen, G.: Development and optimization of a nonlinear multiparameter model for the human operator.
In: Proc. 7$^{th}$ Annual Conf. Manual Control, NASA SP–281 (1972), pp. 15–21

Johannsen G.: Development and optimization of a nonlinear multi–parameter human operator model. IEEE Trans. Systems, Man, Cybernetics, Vol. SMC–2 (1972), pp. 494–504

Dey, D. und G. Johannsen: Anthropotechnische Untersuchung einer Übergrundanzeige und eines künstlichen Horizonts mit Voranzeige zur manuellen Regelung von VTOL–Flugzeugen. Z. Flugwissenschaften, 21 (1973), S. 140–145

Berheide, W. und G. Johannsen: Simulation des Regler–Mensch–Verhaltens in Mensch–Fahrzeug–Systemen. In: Tagungsband Methodik der rechnergestützten Simulation, Kernforschungszentrum Karlsruhe, KFK 1845 (1973), S. 367–374

Johannsen, G.: Application of random search techniques and stochastic approximation in human operator modelling. In: P. Eykhoff (Ed.): Identification and System Parameter Estimation. Amsterdam: North-Holland Publishing Company, 1973, pp. 251–254

Johannsen, G.: Human operator modelling as a tool for system performance evaluation and prediction. In: Proc. 12th DRG Seminar *The Optimum Balance between Man and Machine in Man-Machine Systems*, DS/DR (73) 375, 1973, pp. 173–189

Johannsen, G.: Optimierung vielparametriger Bezugsmodelle mit Hilfe von Zufallssuchverfahren. Regelungstechnik Prozeß-Datenverarbeitung, 21 (1973), S. 234–239

Johannsen, G.: Nebenaufgaben als Beanspruchungsmessverfahren in Fahrzeugführungsaufgaben. Z. Arbeitswissenschaft, 30 (2NF) 1976/1, S. 45–50

Johannsen, G.: Internationales Symposium "Monitoring Behavior and Supervisory Control", Ergebnisse der Arbeitssitzungen. Regelungstechnik, 24 (1976), S. 427–429

Sheridan, T. B. and G. Johannsen (Eds.): Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976, 538 pp.

Johannsen, G.: Preview of man-vehicle control session. In: T. B. Sheridan and G. Johannsen (Eds.): Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976, pp. 3–12

Sheridan, T. B. and G. Johannsen: Workshop reports – Introduction and summary. In: T. B. Sheridan and G. Johannsen (Eds.): Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976, pp. 473–477

Johannsen, G., C. Pfendler, and W. Stein: Human performance and workload in simulated landing-approaches with autopilot-failures. In: T. B. Sheridan and G. Johannsen (Eds.): Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976, pp. 83–95

Johannsen, G., G. Nossing und C. Pfendler: Pilotenbeanspruchung und -leistung in einem simulierten STOL-Anflug. In: DGLR-Bericht 76-01 (Deutsche Gesellschaft für Luft- und Raumfahrt), 1976, S. 111–129

Johannsen, G., H. E. Boller, E. Donges und W. Stein: Lineare Modelle für den Menschen als Regler. Bericht Nr. 24, Forschungsinstitut für Anthropotechnik, Meckenheim, 1976

Johannsen, G.: Internationales Symposium "Monitoring Behavior and Supervisory Control", Kurzbericht und Ergebnisse der Arbeitssitzungen. Z. Arbeitswissenschaft, 31 (3NF) 1977/1, S. 50–52

Berheide, W., G. Johannsen, R. Klein und G. Nossing: Festsitz-Teilsimulator für anthropotechnische Untersuchungen von Landeanflügen. Bericht Nr. 29, Forschungsinstitut für Anthropotechnik, Meckenheim, 1977

Pfendler, C. und G. Johannsen: Beiträge zur Beanspruchungsmessung und zum Lernverhalten in simulierten STOL–Anflügen. Bericht Nr. 30, Forschungsinstitut für Anthropotechnik, Meckenheim, 1977

Rouse, W. B., G. Johannsen, Y.–Y. Chu, T. Govindaraj, J. S. Greenstein, R. S. Walden: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1977

Rouse, W. B., G. Johannsen, Y.–Y. Chu, T. Govindaraj, J. S. Greenstein, R. S. Walden: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1977

Johannsen, G., H. E. Boller, E. Donges und W. Stein: Der Mensch im Regelkreis: Lineare Modelle. Reihe: Methoden der Regelungstechnik. München: Oldenbourg Verlag, 1977, 259 S.

Johannsen, G.: Auslegung von Flugführungsanzeigen mit Hilfe des optimaltheoretischen Modells für den Menschen als Regler. In: Jahrbuch der Deutschen Gesellschaft für Luft– und Raumfahrt (DGLR), 1978, S. 149/1–149/14

Rouse, W. B., G. Johannsen, Y.–Y. Chu, T. Govindaraj, J. S. Greenstein, H. L. Neubauer: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1978

Rouse, W. B., G. Johannsen, Y.–Y. Chu, T. Govindaraj, J. S. Greenstein, H. L. Neubauer: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1978

Johannsen, G. and T. Govindaraj: Analysis of a VTOL hover task with predictor displays using an optimal control model of the human operator. In: Proc. 14th Annual Conf. Manual Control, NASA Conf. Publication 2060, 1978, pp. 237–251

Johannsen, G. and W. B. Rouse: Prospects of a mathematical theory of human behavior in complex man–machine systems tasks. In: Proc. 14th Annual Conf. Manual Control, NASA Conf. Publication 2060, 1978, pp. 137–159

Johannsen, G., N. Moray (Chairman), R. Pew, J. Rasmussen, A. Sanders, C. Wickens: Final report of experimental psychology group.
In: N. Moray (Ed.): Mental Workload: Its Theory and Measurement. New York: Plenum Press, 1979, pp. 101–114

Rouse, W. B., G. Johannsen, S. H. Rouse, T. Govindaraj, J. S. Greenstein, J. M. Hammer: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1979

Johannsen, G. and W. B. Rouse: Mathematical concepts for modelling human behavior in complex man–machine systems. Human Factors, Vol. 21 (1979), pp. 733–747

Johannsen, G.: Überwachungs– und Entscheidungsverhalten des Menschen in Mensch–Maschine–Systemen. Bericht No. 44, Forschungsinstitut für Anthropotechnik, Wachtberg–Werthhoven, 1979

Johannsen, G.: Workload and workload measurement. In: N. Moray (Ed.): Mental Workload: Its Theory and Measurement. New York: Plenum Press, 1979, pp. 3–11

Johannsen, G. and W. B. Rouse: A study of the planning process of aircraft pilots in emergency and abnormal situations.
In: Proc. IEEE Internat. Conf. Cybernetics and Society, 1980, pp. 738–745

Rouse, W. B., G. Johannsen, S. H. Rouse, J. M. Hammer, C. W. Webster: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1980

Rouse, W. B., G. Johannsen, S. H. Rouse, J. M. Hammer: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1980

Johannsen, G.: Manuelle Regelung in Mensch–Maschine–Systemen. Habilitationsschrift, Rheinisch–Westfälische Technische Hochschule, Aachen, 1980 (Auch: Bericht Nr. 45, Forschungsinstitut für Anthropotechnik, Wachtberg–Werthhoven, 1980)

Johannsen, G.: Fault management and supervisory control of decentralized systems. In: J. Rasmussen and W. B. Rouse (Eds.): Human Detection and Diagnosis of System Failures. New York: Plenum Press, 1981, pp. 353–368

Johannsen, G.: Human–computer interaction in decentralized control and fault management of dynamic systems. In: Proc. IFAC 8$^{th}$ Triennial World Congress, Kyoto, 1981. Oxford: Pergamon. (Preprints, Vol. XV, pp. 53–58)

Johannsen, G., W. B. Rouse, and K. Hillmann: Studies of planning behavior of aircraft pilots in normal, abnormal, and emergency situations. Bericht Nr. 53, Forschungsinstitut für Anthropotechnik, Wachtberg–Werthhoven, 1981

Johannsen, G.: Automatisierungstechnik und Mensch–Maschine–Systeme in Japan und China. DFG–Reisebericht, Forschungsinstitut für Anthropotechnik, Wachtberg–Werthhoven, 1981

Rouse, W. B., G. Johannsen, S. H. Rouse, J. M. Hammer, N. M. Morris, C. W. Webster: Pilot interaction with automated airborne decision making systems. Semiannual Progress Report, NASA Grant NSG–2119, Coordinated Science Laboratory, University of Illinois at Urbana–Champaign, 1981

Johannsen, G. and W. B. Rouse: Problem solving behavior of pilots in abnormal and emergency situations. In: Proc. 1st European Annual Conf. Human Decision Making and Manual Control, Delft, 1981, pp. 142–150

Johannsen, G. and H. E. Boller (Eds.): Human Decision Making and Manual Control (Proc. 2nd European Annual Manual Conf.). Wachtberg-Werthhoven: Forschungsinstitut für Anthropotechnik, 1982, 385 pp.

Johannsen, G.: Models for analysis and design of man-machine systems. In: L. Troncale (Ed.): A General Survey of Systems Methodology. Washington, D. C.: Society for General Systems Research, 1982, pp. 230–232

Johannsen G. and J. E. Rijnsdorp (Eds.): Analysis, Design, and Evaluation of Man-Machine Systems (Proc. IFAC / IFIP / IFORS / IEA Conf.). Oxford: Pergamon, 1983, 424 pp.

Johannsen, G.: Man-machine systems – Introduction and background. In: G. Johannsen and J. E. Rijnsdorp (Eds.): Analysis, Design, and Evaluation of Man-Machine Systems. Oxford: Pergamon, 1983, pp. VIII–XVII

Johannsen, G. and C. Pfendler: Mental workload and performance under different degrees of uncertainty in fault management situations. In: Proc. 3rd European Annual Conference on Human Decision Making and Manual Control, Roskilde, 1983, pp. 285–297.

Johannsen, G. and W. B. Rouse: Studies of planning behavior of aircraft pilots in normal, abnormal, and emergency situations. IEEE Trans. Systems, Man, Cybernetics, Vol. SMC-13 (1983), pp. 267–278

Johannsen, G., J. E. Rijnsdorp, and A. P. Sage: Human system interface concerns in support system design. Automatica (Special Issue on Control Frontiers in Knowledge Based and Man-Machine Systems), Vol. 19 (1983), pp. 595–603

Johannsen, G.: Categories of human operator behavior in fault management situations. In: Proc. IEEE Internat. Conference on Systems, Man, and Cybernetics, Bombay / New Delhi, 1983 / 84, pp. 884–889

### From 1984 to 1997

Johannsen, G.: Experimentelle Untersuchung und Modellierung der menschlichen Arbeitstätigkeiten in Fehlermanagement-Situationen. Ortung und Navigation, 25 (1984), S. 671–682

Johannsen, G.: Interaction between controlling, planning, and fault managing in complex man-machine systems. In: Proc. IFAC 9th World Congress, Budapest, 1984. Oxford: Pergamon. (Preprints, Vol. VI, pp. 204–208)

Alty, J. L., P. Elzer, O. Holst, G. Johannsen, and S. Savory: Literature and User Survey of Issues Related to Man-Machine Interfaces for Supervision and Control Systems. ESPRIT P600, Pilot Phase Report. Copenhagen: CRI, 1985

Borchers, H. W., P. Elzer, H. Siebert, C. Weisang, B.–B. Borys, L. Fejes, and G. Johannsen: Survey of Existing Sets of Picture Elements and Editors. ESPRIT–GRADIENT, BBC Heidelberg and GhK Kassel, Bericht Nr. 3, Labor für Mensch–Maschine–Systeme, GhK–Universität, Kassel, 1986

Borys, B.–B., H.–G. Hansel, G. Johannsen, and J. Schmidt: Task and Knowledge Analysis – Methodology and Application in Power Plants. ESPRIT–GRADIENT, Bericht Nr. 2, Labor für Mensch–Maschine–Systeme, GhK–Universität, Kassel, 1986

Borndorff, S., B.–B. Borys, G. Johannsen, J. Schmidt, P. Elzer, H. Siebert, and C. Weisang: Mapping of Power Plant Structures into KEE Elements. ESPRIT–GRADIENT, GhK Kassel und BBC Heidelberg, Bericht Nr. 4, Labor für Mensch–Maschine–Systeme, GhK–Universität, Kassel, 1986

Borys, B.–B., G. Johannsen, H.–G. Hansel, and J. Schmidt: Task and knowledge analysis in coal–fired power plants. In: Proc. IEEE Internat. Conference on Systems, Man, and Cybernetics (Symp. Human–Computer Interaction and Cognitive Engineering), Atlanta, 1986, pp. 766–770

Johannsen, G., B.–B. Borys, and L. Fejes: Ergonomic knowledge support in graphical interface design for industrial process operators. In: Proc. 2nd Symp. Human Interface, Tokyo, 1986, pp. 579–584

Johannsen, G.: Mit ESPRIT in die europäische Zukunft. Universitas, 41 (1986), S. 1020–1022

Johannsen, G.: Vehicular guidance. In: H. P. Willumeit (Ed.): Human Decision Making and Manual Control. Amsterdam: North–Holland, 1986, pp. 3–16

Johannsen, G.: Architecture of man–machine decision making systems. In: E. Hollnagel, G. Mancini, and D. D. Woods (Eds.): Intelligent Decision Support in Process Environments. Berlin: Springer–Verlag 1986, pp. 327–339

Johannsen, G.: Man–Machine Systems, Knowledge Engineering and Related Technologies in Japan. ESPRIT–GRADIENT Bericht, Labor für Mensch–Maschine–Systeme, GhK–Universität, Kassel, 1986

Mancini, G., G. Johannsen, and L. Mårtensson (Eds.): Analysis, Design, and Evaluation of Man–Machine Systems (Proc. 2nd IFAC / IFIP / IFORS / IEA Conf.). Oxford: Pergamon, 1986, 368 pp.

Johannsen, G., J. E. Rijnsdorp, and H. Tamura: Matching user needs and technologies of displays and graphics. In: G. Mancini, G. Johannsen, and L. Mårtensson (Eds.): Analysis, Design, and Evaluation of Man–Machine Systems. Oxford: Pergamon, 1986, pp. 51–61

Johannsen, G. and B.-B. Borys: Investigation of display contents and decision support in a rule-based fault correction task.
In: G. Mancini, G. Johannsen, and L. Mårtensson (Eds.): Analysis, Design, and Evaluation of Man-Machine Systems. Oxford: Pergamon, 1986, pp. 91–97

Alty, J. L., P. Elzer, O. Holst, G. Smart, G. Johannsen, and S. Savory: Literature and user survey of issues related to man-machine interfaces for supervision and control systems.
In: The Commission of the European Communities (Ed.): ESPRIT'85-Status Report of Continuing Work. Amsterdam: North-Holland, 1986, Part 1, pp. 719–729

Alty, J. L. and G. Johannsen: Knowledge based dialogue for dynamic systems.
In: Proc. IFAC 10th World Congress on Automatic Control, München, 1987. Oxford: Pergamon. (Preprints, Vol. 7, pp. 358–367)

Borys, B.-B., G. Johannsen, H.-G. Hansel, and J. Schmidt: Task and knowledge analysis in coal-fired power plants. IEEE Control Systems Magazine, Vol. 7 (1987) 3, pp. 26–30

Johannsen, G., S. Borndorff, and G. A. Sundström: Knowledge elicitation and representation for supporting power plant operators and designers.
In: Preprints, First European Meeting on Cognitive Science Approaches to Process Control, Session 1 / Paper 3, Marcoussis, 1987, pp. 1–10

Johannsen, G.: Fault management, knowledge support, and responsibility in man-machine systems. In: J. A. Wise and A. Debons (Eds.): Information Systems: Failure Analysis. Berlin: Springer-Verlag, 1987, pp. 205–209

Johannsen, G.: Gestaltung von Mensch-Maschine-Systemen in der Fahrzeugführung. Ortung und Navigation, 28 (1987), S. 354–355

Johannsen, G.: Neue Entwicklungen bei Mensch-Maschine-Systemen. Automatisierungstechnik, 35 (1987), S. 385–395

Elzer, P. and G. Johannsen (Eds.): Concepts, Design, and Prototype Implementations for an Intelligent Graphical Editor (IGE1). ESPRIT-GRADIENT, GhK Kassel und BBC Heidelberg, Bericht Nr. 6, Labor für Mensch-Maschine-Systeme, GhK-Universität, Kassel, 1988

Alty, J. L. and G. Johannsen: Knowledge based dialogue for dynamic systems. Automatica, Vol. 25 (1989), pp. 829–840

Stassen, H. G., G. Johannsen, and N. Moray: Internal representation, internal model, human performance model and mental workload. (Plenary paper, Proc. 3rd IFAC / IFIP / IEA / IFORS Conf. on Man-Machine Systems, Oulu).
In: J. Ranta (Ed.): Analysis, Design and Evaluation of Man-Machine Systems. Oxford: Pergamon, 1989, pp. 23–32

Sundström, G. A. and G. Johannsen: Functional information search: A framework for knowledge elicitation and representation for graphical support systems. In: Proc. 2nd European Meeting on Cognitive Science Approaches to Process Control, Siena, 1989, pp. 129–140

Johannsen, G. and J. L. Alty: Knowledge engineering for industrial expert systems. (Plenary Paper, Proc. 4th IFAC / IFIP / IFORS / IEA Conf. on Man–Machine Systems, Xi'an). In: B. S. Hu (Ed.): Analysis, Design and Evaluation of Man–Machine Systems. Oxford: Pergamon, 1990, pp. 1–12

Johannsen, G., B.–B. Borys, G. A. Sundström, L. Fejes, and G. Strätz: Issues of Design Support and User Modelling for Intelligent Graphical Editors, and Presentation System. ESPRIT–GRADIENT, Bericht Nr. 8, Labor für Mensch–Maschine–Systeme (IMAT–MMS), GhK–Universität, Kassel, 1990

Johannsen, G.: Complexity in man–machine systems. In: Proc. IFAC 11th World Congress on Automatic Control, Tallinn, 1990. Oxford: Pergamon. (Preprints, Vol. 1, pp. 241–242)

Johannsen, G.: Design issues of graphics and knowledge support in supervisory control systems. In: N. Moray, W. R. Ferrell, and W. B. Rouse, (Eds.): Robotics, Control and Society. London: Taylor & Francis, 1990, pp. 150–159

Johannsen, G.: Dritter Workshop über "Grundlagen für den Einsatz von Expertensystemen in der Automatisierungstechnik". Automatisierungstechnik, 38 (1990), S. 189–193

Johannsen, G.: Fahrzeugführung. In: C. Graf Hoyos und B. Zimolong (Hrsg.): Ingenieurpsychologie. Enzyklopädie der Psychologie, Band D/III/2. Göttingen: Verlag für Psychologie, Hogrefe, 1990, S. 426–454

Johannsen, G.: Knowledge analysis in power plants. In: M. G. Singh (Ed.): Systems and Control Encyclopedia, Supplementary Volume 1 (Advances in Systems, Control and Information Engineering). Oxford: Pergamon, 1990, pp. 366–373

Johannsen, G.: Towards a new quality of automation in complex man–machine systems. In: Proc. IFAC 11th World Congress on Automatic Control, Tallinn, 1990. Oxford: Pergamon. (Preprints, Vol. 10, pp. 175–181)

Stassen, H. G., G. Johannsen, and N. Moray: Internal representation, internal model, human performance model and mental workload. Automatica, Vol. 26 (1990), pp. 811–820

Fejes, L., G. Johannsen, and G. Strätz: Graphical editor and process visualisation system for dynamic systems. In: Proc. Eurographics '91 (Graphics R&D in EC Programmes), Wien, 1991, pp. 67–81

Fejes, L., G. Johannsen, and G. Strätz: Hierarchical data structure for dynamic visual systems. In: Proc. 2nd IFIP Conference on Visual Database Systems, Budapest, 1991. (Preprints, pp. 221–235)

Johannsen, G. and J. L. Altу: Knowledge engineering for industrial expert systems. Automatica, Vol. 27 (1991), pp. 97–114

Johannsen, G.: Integrated automation in complex man–machine systems (invited plenary paper). In: Proc. European Control Conference (ECC 91), Grenoble, 1991. Paris: Hermès, Vol. 2, pp. 1013–1021

Inagaki, T. and G. Johannsen: Human–computer interaction and cooperation for supervisory control of large–complex systems. In: Proc. Eurocast '91 (2nd Internat. Workshop on Computer Aided Systems Theory), Krems, 1991 (Lecture Notes in Computer Sciences, Vol. 585. Berlin: Springer–Verlag, 1992, pp. 281–294)

Johannsen, G., A. H. Levis, and H. G. Stassen: Theoretical problems in man–machine sytems and their experimental validation (plenary paper). In: Proc. 5th IFAC / IFIP / IFORS / IEA Symp. on Analysis, Design and Evaluation of Man–Machine Systems, The Hague, 1992. (Preprints, pp. 0.0.3 / 1–11)

Johannsen, G.: Simulated man–machine systems as computer–aided information transfer and self–learning tools. In: Proc. Internat. Symp. on Expanding Access to Science and Technology – The Role of Information Technologies, Kyoto University / United Nations University, Kyoto, 1992 (Proc. 1994, pp. 195–213)

Johannsen, G.: Towards a new quality of automation in complex man–machine systems. Automatica, Vol. 28 (1992), pp. 355–373

Johannsen, G.: Mensch–Maschine–Systeme <Human–Machine Systems, in German>. Berlin: Springer–Verlag, 1993, 588 S.

Ali, S., J. Heuer, M. Hollender, and G. Johannsen: Participative design of human–machine interfaces for process control systems. In: Adjunct Proc. INTERCHI' 93 (Conf. on Human Factors in Computing Systems), Amsterdam, 1993, pp. 53–54

Borndorff–Eccarius, S. and G. Johannsen: Supporting diagnostic functions in human supervisory control. In: Proc. Internat. Conf. Systems, Man and Cybernetics, Le Touquet, 1993, Vol. 2, pp. 351–356

Johannsen, G. and E. A. Averbukh: Human performance models in control. In: Proc. Internat. Conf. Systems, Man and Cybernetics, Le Touquet, 1993, Vol. 4, pp. 397–402

Fejes, L., G. Johannsen, and G. Strätz: A graphical editor and process visualisation system for man–machine interfaces of dynamic systems. The Visual Computer, Vol. 10 (1993) 1, pp. 1–18

Johannsen, G. and B.–B. Borys (Eds.): Human Decision Making and Manual Control (Proc. 12th European Annual Manual Conf.). University of Kassel, 1993. Kassel: Institut für Mess– und Automatisierungstechnik

Johannsen, G. and E. A. Averbukh: General Man–Machine Interface Organisation. Internal Report No. IR1–02, BRITE / EURAM–Project No. 6126. Labor Man–Machine Systems, University of Kassel, 1993

Johannsen, G.: Knowledge based design of human–machine interfaces. In: Proc. IFAC 12th World Congress on Automatic Control, Sydney, 1993. Oxford: Pergamon. (Preprints, Vol. 8, pp. 343–347)

Johannsen, G.: Design of intelligent human–machine interfaces (invited plenary paper). In: Proc. 3rd IEEE International Workshop on Robot and Human Communication, Nagoya, 1994, pp. 18–25

Johannsen, G.: Knowledge–based support for design and operational use of human–machine interfaces (invited plenary paper). In: Proc. Specialists' Meeting on Application of Artificial Intelligence and Robotics to Nuclear Plants (AIR'94), Tokai–mura, 1994, pp. 261– 270

Johannsen, G.: Leitende Kontrolle und integrierte Automation in Mensch–Maschine–Systemen. In: K.–P. Gärtner, W. Stein und H. Widdel (Hrsg.): Mensch–Maschine–Systeme und Neue Informationstechnologien. Aachen: Augustinus Verlag, 1994, S. 245–251

Averbukh, E. A. and G. Johannsen: Intelligent human–machine communication and control for industrial processes. In: Proc. First Asian Control Conference (ASCC), Tokyo, 1994, Vol. 1, pp. 49–52

Averbukh, E. A. and G. Johannsen: Knowledge–based interface systems for human supervisory control. In: Proc. Japan–CIS Symposium on Knowledge Based Software Engineering '94, Pereslavl–Zalesski, 1994, pp. 229–232

Averbukh, E. A., G. Johannsen, F. Mletzko, R. van Paassen, J. Rudewig, and V. Stefanuk: Toolkit Architectural Design. Internal Report D4–2, BRITE / EURAM Project No. 6126. Labor Man–Machine Systems, University of Kassel, 1994

Johannsen, G. and E. A. Averbukh: Human interaction for process supervision based on end–user knowledge and participation. In: Proc. Symposium on Artificial Intelligence in Real–Time Control (AIRTC'94), Valencia, 1994, pp. 255–260

Johannsen, G., (Ed.): Integrated Systems Engineering (Proc. IFAC Conf.). Oxford: Pergamon, Elsevier Science, 1994 (Preprints, 484 pp.)

Johannsen, G.: Integrated systems engineering: The challenging cross–discipline (invited plenary paper). In: G. Johannsen (Ed.): Integrated Systems Engineering. IFAC Conference, Baden–Baden, 1994. Oxford: Pergamon, Elsevier Science. (Preprints, pp. 1–10)

Johannsen, G., A. H. Levis, and H. G. Stassen: Theoretical problems in man–machine systems and their experimental validation. Automatica, Vol. 30 (1994), pp. 217–231

Johannsen, G., E. A. Averbukh, F. Mletzko, R. van Paassen, J. Rudewig, T. Gavrilova, and A. Voinov: Toolkit Detailed Architectural Design. Issue 2. Internal Report D5–1, BRITE / EURAM–Project No. 6126. Labor Man–Machine Systems, University of Kassel, 1995

Johannsen, G., S. Ali and J. Heuer: Human–machine interface design based on user participation and advanced display concepts.
In: Proc. Post–HCI '95 Conference Seminar on Human–Machine Interface in Process Control, Hieizan, Japan, 1995, pp. 33–45

Johannsen, G.: Human–machine interfaces for cooperative work.
In: Y. Anzai, K. Ogawa, H. Mori (Eds.): Symbiosis of Human and Artifact (Proc. 6th Internat. Conf. Human–Computer Interaction, Yokohama).
Amsterdam: Elsevier, 1995, Vol. 20A, pp. 359–364

Johannsen, G.: Knowledge based design of human–machine interfaces. Control Engineering Practice, Vol. 3 (1995), pp. 267–273

Johannsen, G.: Computer–supported human–machine interfaces. Journal of the Society of Instrument and Control Engineers (SICE) of Japan, Vol. 34 (1995), pp. 213–220

Johannsen, G.: Conceptual design of multi–human machine interfaces (invited plenary paper).
In: Proc. 6th IFAC / IFIP / IFORS / IEA Symposium on Analysis, Design and Evaluation of Man–Machine Systems. MIT, Cambridge, MA, 1995, pp. 1–12

Johannsen, G.: Cooperative human–machine interfaces for plant–wide control and communication (survey paper). In: Proc. 13th World Congress International Federation of Automatic Control (IFAC '96), San Francisco, CA, 1996. Oxford: Pergamon. (Preprints, Vol. L, Session 5b–02, pp. 355–366)

Tiemann, M., E. A. Averbukh, and G. Johannsen. Evaluation and Measurement Procedure. Internal Report D4 DIAMANTA, Esprit Project 20507. Lab. Systems Engineering and Human–Machine Systems, University of Kassel, 1996

Tiemann, M., E. A. Averbukh, and G. Johannsen. Synthesis of Evaluation and Measurements. Internal Report D5 DIAMANTA, Esprit Project 20507. Lab. Systems Engineering and Human–Machine Systems, University of Kassel, 1996

Averbukh, E. A., F. Mletzko, and G. Johannsen: Man–Machine Interface Design Methodology. Internal Report D4–1, BRITE / EURAM–Project No. 6126. Labor Man–Machine Systems, University of Kassel, 1996

Averbukh, E. A., G. Johannsen, J. Kwaan, B. L. Olesen, G. Zardetto, and M. Caimi: Synthesis Report. BRITE / EURAM–Project No. 6126. Labor Man–Machine Systems, University of Kassel, 1996

Johannsen, G.: Cognition space metaphor for human–machine interaction. In: Proc. Cognitive Systems Engineering in Process Control (CSEPC 96 Conference), Kyoto, 1996, pp. 253–260

### Since 1997

Johannsen, G.: Conceptual design of multi–human machine interfaces. Control Engineering Practice, Vol. 5 (1997), No. 3, pp. 349–361

Johannsen, G.: Cooperative human–machine interfaces for plant–wide control and communication. In: J. J. Gertler (Ed.): Annual Reviews in Control, Vol. 21. Oxford: Pergamon, Elsevier Science, 1997, pp. 159–170

Johannsen, G., S. Ali, and R. van Paassen: Intelligent human–machine systems. In: S. Tzafestas (Ed.): Methods and Applications of Intelligent Control. Dordrecht: Kluwer, 1997, pp. 329–356

Johannsen, G., J. Heuer, and M. Tiemann: Participative user interface design for industrial processes. In: Proc. The Silicon Valley Ergonomics Conference (ErgoCon'97), Palo Alto, CA, 1997, pp. 21–28

Johannsen, G.: Gruppovie tcheloveko machinnie interfeisi dlya upravleniya i obschscheniya v maschtabe predpriyatiya <Cooperative human–machine interfaces for plant–wide control and communication, in Russian>. Pribori i Sistemi Upravleniya <Instruments and Control Systems>, 1997, No. 6, pp. 50–58

Johannsen, G.: Human–computer interfaces for supervisory control. In: T. B. Sheridan and T. van Lunteren (Eds.): Perspectives on the Human Controller. Mahwah, NJ: Lawrence Erlbaum, 1997, pp. 261–270

Borys, B.–B. and G. Johannsen: An experimental multimedia process control room. In: Proc. Annual Conference 1997: Human Factors and Ergonomics Society Europe Chapter, Advances in Multimedia and Simulation, Bochum, 1997, pp. 276–289

Borys, B.–B., G. Johannsen, C. Wittenberg and G. Strätz (Eds.): Human Decision Making and Manual Control (Proc. 16th European Annual Manual Conf.). Kassel: Institut für Mess– und Automatisierungstechnik (IMAT), University of Kassel, 1997, 284 pp.

Averbukh, E. A. and G. Johannsen: Systemergonomische Entwicklung von interaktiven Systemen unter besonderer Berücksichtigung des Usability Engineering für die Mensch–Prozeß–Kommunikation. In: Tagungsband VDE–Kongreß '98, GMA–Fachtagung, Stuttgart, 21.–22. Okt. 1998, pp. 55–63

Dimitrova, M., G. Johannsen, H. A. Nour Eldin, J. Zaprianov, and M. Hubert: Adaptivity in human–computer interface systems: Identifying user profiles for personalised support. In: Proc. 7th IFAC / IFIP / IFORS / IEA Symp. on Analysis, Design and Evaluation of Man–Machine Systems, Kyoto, Japan, Sept. 16–18, 1998. Oxford: Pergamon, pp. 467–472

Johannsen, G.: Advanced visualisation and multimedia approaches for process control. In: Proc. Post IFAC–MMS '98 Conference Seminar on Human with Technology, Mihama, Fukui, Japan, Sept. 21–22, 1998, pp. 36–38

Johannsen, G.: Human–computer communication for design and operation in performing arts and industrial engineering. In: Proc. 7th IFAC / IFIP / IFORS / IEA Symp. on Analysis, Design and Evaluation of Man–Machine Systems, Kyoto, Japan, Sep. 1998. Oxford: Pergamon, Elsevier Science, pp. 41–46

Johannsen, G.: Moderne Mensch–Maschine–Kommunikation. In: Tagungsband des 14. Österreichischen Automatisierungstages, Wien, 28. Sept. 1999, S. 1–13

Johannsen, G.: Sound communication in a multi–agent human–robot environment. In: Preprints 1st IFAC Workshop on Multi–Agent–Systems in Production, Vienna, Austria, Dec. 2–4, 1999, pp. 49–52

Johannsen, G.: Human–centred life–cycle methodology for the development of model–based user interfaces. In: Abstracts CSM '99 – 13th JISR–IIASA Workshop on Methodologies and Tools for Complex System Modeling and Integrated Policy Assessment, IIASA, Laxenburg, Austria, Sep. 1999, pp. 25–28

Johannsen, G.: Visual and auditory displays in human–computer interaction. In: Proc. 2nd International Conference on Human and Computer – HC–99, University of Aizu, Aizu–Wakamatsu and Tokyo, Japan, Sep. 1999, pp. 19/1–19/7

Johannsen, G.: Visual and auditory displays in human–computer interaction. 3D Forum – The Journal of Three Dimensional Images (Japan), Vol. 13 (1999), No. 3, pp. 47–53

Johannsen, G.: Analysis of audio symbols based on musical and robot–movement sounds using time–frequency methods.
In: H. G. Feichtinger, M. Dörfler (Eds.): Diderot Forum on Mathematics and Music, Vienna, Austria, Dec. 2–4, 1999, pp. 215–226

Johannsen, G.: Design and understandability of digital–audio musical symbols for intent and state communication from service robots to humans.
In: Proc. 2nd COST–G6 Workshop on Digital Audio Effects (DAFx99), Trondheim, Norway, Dec. 9–11, 1999, pp. 171–174

Johannsen, G.: Audiovisuelle Informationsdarbietung in Assistenzsystemen für die Fahrzeugführung.
In: Fortschritt-Berichte VDI, Symposium "Automatisierungs- und Assistenzsysteme für Transportmittel", Braunschweig, 2.–3. März 2000, S. 25–36

Johannsen, G.: Auditory displays in human-machine interfaces of mobile robots for non-speech communication with humans.
In: I. Troch, F. Breitenecker (Eds.): Proc. 3rd MATHMOD, IMACS Symposium on Mathematical Modelling, Invited Session "Human-Machine Interfaces in Robotics," Vienna, Austria, Febr. 2000, Vol. 1, pp. 47–50

Johannsen, G.: Cognitive systems analysis, design, and experimental investigation of auditory displays for human-machine interfaces.
In: Proc. CSEPC 2000 International Conference on Cognitive Systems Engineering in Process Control, Taejon, Korea, Nov. 22–25, 2000, pp. 150–155

Johannsen, G., O. Werner, and P. Zerweck (Eds.): Human Supervision and Control in Engineering and Music (Preprints Internat. Workshop). Kassel: IMAT-Laboratory for Systems Engineering and Human-Machine Systems, University of Kassel, 2001, 287 pp.

Johannsen, G.: Short Description of the International Workshop Human Supervision and Control in Engineering and Music. In: G. Johannsen, O. Werner, P. Zerweck (Eds.) Human Supervision and Control in Engineering and Music (Preprints Internat. Workshop, pp. 9–15). Kassel: IMAT-Laboratory for Systems Engineering and Human-Machine Systems, University of Kassel, 2001

Johannsen, G.: Auditory displays in human-machine interfaces of mobile robots for non-speech communication with humans. Journal of Intelligent and Robotic Systems, Vol. 32 (2001), No. 2, pp. 161–169

Johannsen, G. (Ed.): Analysis, Design, and Evaluation of Human-Machine Systems (Proc. 8th IFAC / IFIP / IFORS / IEA Symposium, Kassel, 2001; Preprints, 687 pp.). Oxford: Elsevier Science, 2002

Johannsen, G.: Human-machine systems research for needs in industry and society. In: G. Johannsen (Ed.) Proc. 8th IFAC / IFIP / IFORS / IEA Symp. on Analysis, Design, and Evaluation of Human-Machine Systems, Kassel, Sep. 2001 (Preprints, pp. 1–11). Oxford: Elsevier Science, 2002

spine of the printed book: 17 mm thickness

Kasseler Personalschriften 1 From Muscles to Music

ISBN 3-933146-87-9