HUMAN-MACHINE INTERACTION

Gunnar Johannsen
Department of Mechanical Engineering, University of Kassel, Germany

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Summary

Human-machine interaction is described as the interaction and communication between human users and a machine, a dynamic technical system, via a human-machine interface. The real-time aspect distinguishes the fields of human-machine systems and human-computer interaction which are otherwise strongly related. Research in human-machine interaction has been performed for more than 50 years. Good designs of human-machine interaction and systems have gained a high market value for many products and services in application domains such as industrial, transportation, medical, and entertainment systems.

The main human task categories in human-machine interaction are controlling and problem solving. Controlling comprises continuous and discrete tasks of open- and

closed-loop activities whereas problem solving includes the higher cognitive tasks of fault management and planning.

In this chapter human-machine interfaces are introduced with traditional and advanced functionalities. Presentation, dialogue, and control input are the more traditional levels.

Advanced functionalities provide explanation and adaptability based on user and application models. Dialogue systems and control devices are explained. The presentation issues are elaborated with different types of displays.

The visual displays use computer graphics for process visualization through topological, component-oriented views with dynamic pictures. Complementary views can supply functional knowledge. Auditory displays are becoming more important, with indicating alarms and state information, also as a means for avoiding visual overload. The integration into multimedia leads to multimodal displays.

Knowledge-based systems for decision support are another advanced means for improving human-machine interaction. Procedural support and human error prevention are examples for user-oriented functionalities.

Fault management support, particularly the diagnosis of technical failures, exemplifies application-oriented functionalities. The design and the evaluation of human-machine systems components are outlined with task orientation and different forms of user participation.

1. Introduction

Human-machine interaction with industrial plants and other dynamic technical systems has nowadays been recognized as essential for process safety, quality, and efficiency. It comprises all aspects of interaction and communication between human users and their machines via human-machine interfaces.

The whole system of human users, the human-machine interface, and the machine is the so-called human-machine system (HMS); see Figure 1. Different human user classes may be involved, namely, operators, engineers, maintenance personnel, and managers. They have different but overlapping information needs.

The term “machine” indicates any kind of dynamic technical system (or real-time application), including its automation and decision support equipment and software – and it relates to many diverse application domains. The automation components of the technical system are denoted as supervision and control systems.

They interact directly with the pure technical (production) process. Examples of such processes are a power generation process, a chemical or a discrete-parts production process, an aircraft, a tele-manipulator or a real-time software application.

The decision support systems are more advanced, knowledge-based functionalities of the machine which provide advice for the human users.

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Figure 1: The whole human-machine system (HMS) with human users, human-machine interface, and the machine.

The application domains include all kinds of industrial, transportation, medical, service, home, and entertainment systems. The more traditional application domains of industrial and transportation systems have nowadays been supplemented by application domains from medical to entertainment systems. All application domains profit from advancements in the development of the human-computer interaction field. Human-computer interaction (HCI) is characterized as human interaction with those computer application domains which are not determined by a dynamic process or by real-time constraints, as it is always the case in human-machine interaction (HMI).

The degree of automation in control of dynamic technical systems has substantially been increased over the last decades. This is true for all technical systems such as power plants, industrial production plants, and vehicles and transportation systems. High levels of safety, performance, and efficiency have been achieved by means of the increased use of automatic control. Interestingly enough – however, with no surprise to human factors specialists – the need for improved human-machine communication increased (rather than decreased) with the increased degree of automation. Generally, increased automation does not replace the human users who are interacting with the machine, but shifts the location of the interface between both. The machine as an automated system becomes more complex than one with less automation, leading to more sophisticated structures of supervisory control. Higher complexity and more sophisticated control structures require a new quality of communication and co-operation between human and machine. The role of the human user shifts from that of a controller to that of a supervisor. The human supervisor interacts with the process through one or several layers of computers on which the human-machine interface, the automation, and the decision support functionalities are implemented.

Thus, the functionalities of well-designed human-machine interaction have gained predominant importance in advanced process control as a consequence of the degree of automation and, also, of the increase of extended automation functionalities. The advanced technologies with extended functionalities include expert systems for control and diagnostics, fuzzy process control, and artificial neural networks in process control. It is important to ensure integration between conventional control systems and these advanced technologies for the purpose of reaching the overall goals of efficient and safe systems performance as well as sustained and satisfying human performance.

Matching the efforts of automation and of human factors issues leads to the approach of human-centered automation, recommended by many researchers for quite a long time. Today, it is also more and more followed in industry. Under the perspective of human-

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centered automation and human-centered design, human-machine interaction appears to be a symbiotic process between the human users and their machines via human-machine interfaces whereby both – machines and interfaces – have properly been designed. The functionalities of both, the machine and the interface, have to be specified and designed with a strong view on human-centeredness, i.e., with respect to user orientation – concerning human cognitive processes, human needs, and human capabilities – and based on goal orientation and task orientation. Then, these functionalities can be implemented as extended automation modules and knowledge-based decision support systems within the machine and as interaction and communication modules within the human-machine interfaces. Computer graphics, multimedia and multimodal displays, as well as knowledge-based and other software technologies offer a wide range of alternative designs for human-machine interfaces, extended automation, and knowledge-based support.

Human-machine interaction is goal-oriented. The overall goals of human-machine systems are mainly (1) productivity goals, (2) safety goals, (3) humanization goals, and (4) environmental compatibility goals. The productivity goals include economic as well as product and production quality goals. The importance of the safety goals is strongly influenced by the application domain. This goal class dominates all others in many large-scale systems and, particularly, in risky systems. The humanization goals comprise team and work organization, job satisfaction, ergonomic compatibility, and cognitive compatibility. The latter includes the sub-goals of transparency and human understanding. The environmental compatibility goals refer to the consumption of energy and material resources as well as to impacts on soil, water, and air.

Human-machine interaction and human-machine systems research require multi-disciplinary or interdisciplinary views and approaches. The following three domains contribute to human-machine interaction and systems research: (1) cognitive science and ergonomics (as the human sciences), (2) automation and systems engineering (as the systems sciences), and (3) information and communication engineering (as the computer sciences). Further, organizational and cultural aspects are strongly involved.

Human-machine systems research has now been performed for about 60 years. Nevertheless, it took quite some time before the human-machine systems field became an established and more widely accepted discipline, particularly also in industries. For long time, mainly the aeronautics and astronautics industries and, to a lesser extent, the car manufacturing industries showed some more interest. This situation has now totally changed. It has been recognized that a good symbiosis between human and machine is generally required. Good human-machine interaction and systems designs have gained a high market value for almost all products and services. Consequently, strong needs in industry and society exist today as an important application pull. This influences the human-machine systems field which became mature but continues, at the same time, as an innovative and always further developing research area.

2. Human Tasks with Automation and Control

It is important to consider cognitive capabilities and information processing behavior of human users interacting with the technical systems, as well as the tasks to be performed

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within any human-machine system, before and beyond all technological possibilities. Task orientation and human-centered designs are necessary for improved operational use of technical processes and their human-machine interaction.

Any user-oriented design of interactive products, such as human-machine systems, should start with definitions of user classes, overall goals and means for their achievement, as well as with task analyses, in order to have a solid basis for user requirements and systems specifications, particularly also for the functional specifications of the human-machine systems components and functionalities. User requirements should consider the goals-means-tasks relationships, and should be based on a task-oriented perspective.

Two principal task categories can comprise all human activities in human-machine systems, namely controlling and problem solving. All other tasks such as monitoring and communicating can be classified as subtasks or supporting tasks. Figure 2 shows a schematic block diagram of a conceptual human performance model together with the automated technical system with their interactions via control devices and displays for controlling and problem solving with respect to prescribed goals which have to be matched by the system's outputs. Controlling comprises continuous and discrete tasks of open-loop and closed-loop activities. The higher cognitive tasks of problem solving include fault management (with fault detection, diagnosis, compensation, and correction) as well as planning. The two task categories require a different selection of information about goals and systems outputs. While the perception of deviations between goals and outputs is normally sufficient for controlling, both types of inputs have to be interpreted more consciously for problem solving tasks. Further, the problem solving tasks are much more knowledge-based activities than the controlling tasks.

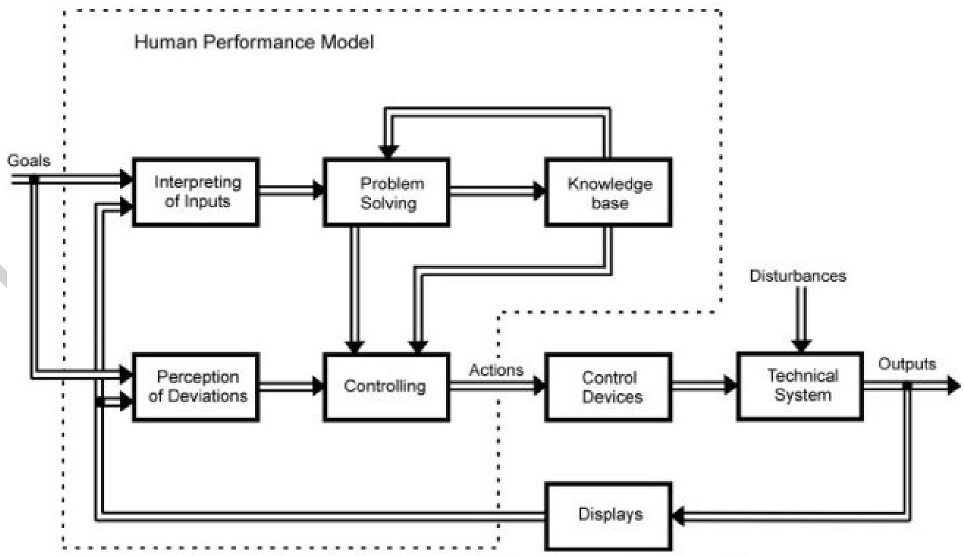

Figure 2: Human performance model with controlling and problem solving, interacting with the automated technical system (after Johannsen, 1992).

Roughly speaking, the two human task categories of controlling and problem solving correspond to the two categories of computer use in advanced automated technical systems, namely computer control (by supervision and control systems) and computer support (by decision support systems); see also Figure 3. This includes the more traditional levels of automation systems as well as all levels of knowledge-based systems. Only since the latter became a more mature technology over the last years, the possibilities of function and task allocations between human operators and computers allow us to relate both human task categories to corresponding categories of computer use. That means also that truly human-centered designs of human-machine systems can now better be pursued and implemented with the latest technology of knowledge support.

The interactions between supervision and control systems, decision support systems, and human operators have to be carried out in such a way that goals and their subgoals are achieved with respect to the technical process and the overall system. The goals and appropriate goal structures are either prescribed or derived by the human operators. Thus, some of the major responsibilities of human operators are the selection of goals and subgoals, the formation of goal structures, and the checking of goal accomplishment and subgoal compatibility.

A closer look at the two task categories of controlling and problem solving shows similarities and differences between their human form and its automated counterpart. The behavior of human operators and, in principle, also of automation systems can be classified into the three information processing phases of categorization, planning, and action. These three phases have to be accomplished in all controlling and problem solving tasks, either on a state-oriented, context-oriented or structure-oriented level. Here, context refers to the fields of information involved. The three levels correspond with the cognitive levels of skill-based, rule-based, and knowledge-based human behavior.

Human operators of technical systems can much more flexibly maneuver through all these different possibilities than the automation systems. However, they may be under time pressure or otherwise impaired or overloaded in certain, particularly critical situations. Therefore, the state of computerization of the technical systems has often been developed quite far. This again has sometimes led to the so-called “ironies of automation”. For example, boredom may occur in normal situations with highly automated systems, and boredom may lead to loss of vigilance, poor job satisfaction, and possibly human errors. Human-centered designs of automated technical systems have to avoid these effects by choosing a flexible function and task allocation between human operators, automation systems for supervision and control, and knowledge-based systems for decision support under all normal, abnormal, and emergency conditions.

The issues of human-machine interaction are not only concerned with the interaction between a single human and the dynamic technical system, the machine. Real work situations in many application domains require that several humans of different human user classes frequently interact with the same technical system and communicate with each other. Some examples of such technical systems are chemical plants, cement plants, power plants, transportation systems, and discrete manufacturing systems.

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In plant-wide control and communication, several partially overlapping groups exist. Their official hierarchical structure is often complemented by an informal heterarchical or even flexible opportunistic organization, dependent on company cultures, social and personal preferences, and specific work requirements. As an example, the application domain of the cement industry shows that several persons from different human user classes need to co-operate, in the plant control room or, also, in office rooms during group meetings. These people from different human user classes share their overlapping skills and knowledge, and interact with each other, at least partially, via the human-machine interfaces or directly face-to-face, in addition to communicating with the technical system also via the human-machine interface.

3. Human-Machine Interfaces

3.1. Traditional and Advanced Functionalities

The human-machine interface provides the information links between one or several human users and the machine (i.e., the technical system or application). This is shown in Figure 3. Therein, the four main classes of human users are exemplified, namely operators, engineers, maintenance personnel, and managers. The machine consists of its technical process, as well as its supervision and control systems for automation, its decision support systems for knowledge-based advice, and its data and knowledge libraries.

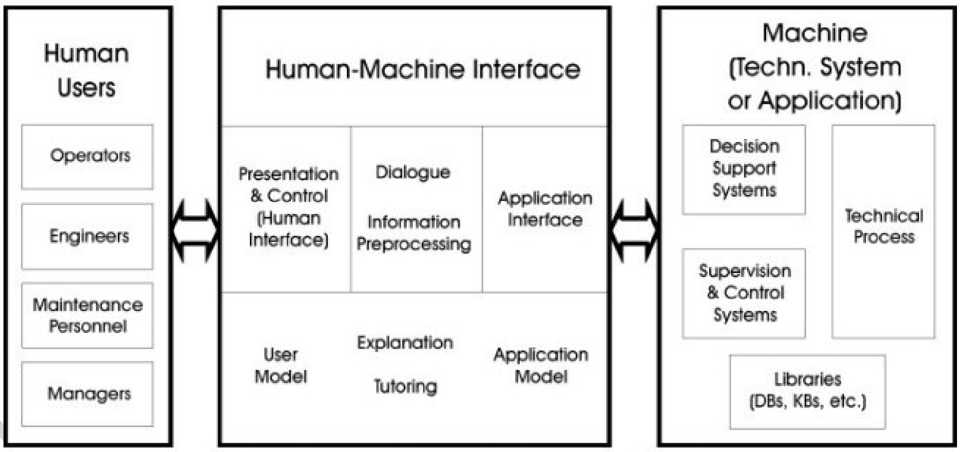

Figure 3: Main functionalities of the human-machine interface between human users and the machine (after Johannsen, 1997b; and Johannsen, Heuer, and Tiemann, 1997).

As also outlined in Figure 3, the human-machine interface is subdivided into components for presentation and control (as the human interface), dialogue and information preprocessing, and the application interface as the more traditional functionalities, and into user model, explanation and tutoring, and application model components as the more advanced functionalities. The latter include also new approaches towards improved information preprocessing.

The more traditional levels of human-machine interfaces, such as presentation and dialogue, are generally separable from each other. The presentation and control level is concerned with the problems of how to present the information to the human users, and how to transform their control inputs to the machine. The dialogue level deals with the information flows regarding such problems as what information to handle when, i.e., the handling of the adequate information at the appropriate time, between the human users and all other components of the whole human-machine system. Information preprocessing is more and more often applied in order to provide improved information context and, hence, to facilitate the information processing activities of the human users.

The presentation and control level can also be viewed as the human interface in the narrower sense, on the human side. It is contrasted by the pure technological application interface on the machine side. Generally, visual, auditory (non-speech sound and speech), gestural, mimic (including face-to-face), and haptic (sense of touch) information as well as vibrations can be used as forms of display for presentation.

Combinations lead to multimedia and multimodal displays which will become more important in the future. Currently however, the main mode of presentation is still the visualization, and the graphical user interface is and will be, for some time, predominant. In former times, visual displays were implemented with electromechanical instruments. Today, they are replaced by computer graphics systems which contain a lot of graphical and textual dynamic pictures. These pictures are created with dynamic graphical editors.

Functional displays have been derived from the more traditional visual displays. They include new information preprocessing modules for a better consideration of user and goal orientations. Thereby, these displays realize more advanced functionalities.

Both, the presentation and the dialogue levels can explicitly depend in their functionalities on the goals of the system as well as on knowledge-based technical systems or application models, user or operator models, and task models. The more explicit representation of such models in the human-machine interface leads to more advanced paradigms. An application model contains the knowledge about the goals, the structure and the functions of a particular application. The functionality of this application or technical systems model internally supports all the other functionalities of the human-machine interface.

A user model functionality is needed if a certain adaptability to human user classes or single users shall be achieved. This is the major ingredient for adaptive interfaces. A more elaborated user model will always include a technical systems model in order to represent the user's view with respect to the technical system. In addition, knowledge on human information processing behavior and cognitive strategies has to be represented in a user model by means of algorithms, rules, and, possibly, active inference mechanisms.

Another knowledge-based functionality of a human-machine interface is the explanation functionality. It is a kind of knowledge-based online help system which informs the human users on request about what the components of the technical system (and possibly also of the human-machine interface) mean and how they function. A tutoring functionality supplies even more knowledge in an interactive way to novices and occasional users.

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3.2. Dialogue Systems

The dialogue functionality of Figure 3 can be designed as a quite complicated goal-oriented component for handling the dialogue between the human users and all other components and subcomponents of the human-machine interface and of the technical system. Among other subfunctionalities, this includes the resolution of possible conflicts between different components with respect to dialogue requests to and from the human users.

Different paradigms exist for the dialogue functionality in human-machine interfaces. Three possible roles of the dialogue functionality are differentiated here. With the first paradigm, the dialogue system is a kind of knowledge-based intermediary between the presentation system and both the supervision and control system as well as the decision support system as parts of the technical system. Below, this paradigm will be explained a little further.

The second paradigm of the dialogue functionality exemplifies the dialogue as a communication language or mechanism between the human users and all the subsystems of the technical system. This kind of implicit view on the dialogue in human-machine communications can often be found in the literature. Direct manipulation and menu selection are communication mechanisms which are suitable for dialogues between human users and dynamic technical systems. The third paradigm understands the dialogue system as a co-operative assistant to the presentation system. In this case, the dialogue system is a kind of controller or manager for the information flows through the presentation system.

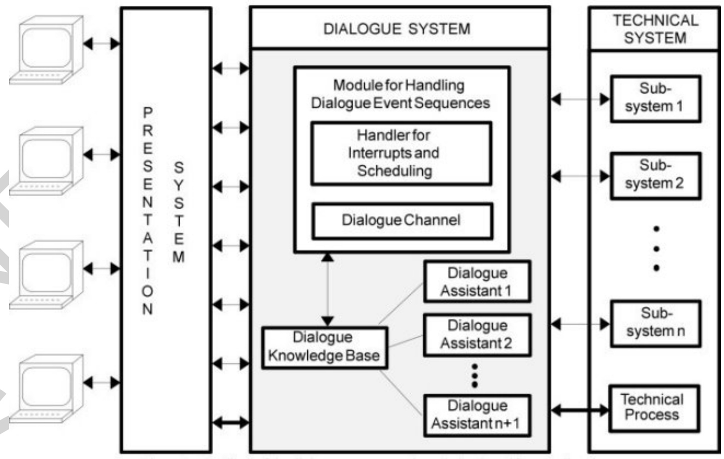

Figure 4: Paradigm of the dialogue system as a knowledge-based intermediary between presentation system and technical system (after Alty and Johannsen, 1989).

An example for the first paradigm is shown in some more detail in Figure 4. A module for handling dialogue events and dialogue event sequences connects all the subsystems of the technical system with the presentation system. Urgent requests, such as alarm messages, from some subsystems, as well as urgent requests from the human users, may interrupt currently ongoing dialogues with other subsystems. Then, the dialogue channel is correspondingly switched by the handler for interrupts and scheduling. Thereby, loose ends of non-terminated (because interrupted) dialogues may occur. By means of a dialogue knowledge base, the human user can be supported in resuming such loose ends of dialogue. Dedicated dialogue assistants aid with time- and contents-related knowledge about their respective technical subsystems. The time aspect and the question of how much knowledge of the subsystems needs to be held locally by the dialogue assistants, depend heavily on the task situations.

3.3. Control Devices

A very broad spectrum of control functionalities as possibilities of control input in human-machine interaction exists. Different forms of control can be exerted, either direct (e.g., gestural as with the conductor of an orchestra), via bio-signals or via control devices. Control via bio-signals is of particular value for handicapped people, e.g., in the operation of an arm prosthesis. Speech and motion (displacements, forces, and gestures) can be used directly or via control devices. Speech input and gestural control will eventually become new means of control in the future.

A few operational systems are already in use. Speech recognition allows the automatic interpretation of the human voice, based on models for phonemes which are the small units of sound in any word and sentence. This technology has great potential for human control of computers and machines, once the recognition rate and the speaker independence can be further increased. Gestural control has been developed with music technologies and in engineering. Currently, it is an emerging subject of research including gesture sensing/capture technologies, intention/emotion detection, mapping strategies, etc.

The predominant form of control in human-machine interaction is the one using control devices. Important types of control devices are keyboards (with alphanumeric or with functional keys), mouse, joystick, trackball, steering wheel, pedals, knobs, and switches. Force-displacement characteristics of these control devices need to be appropriately designed. Also, some virtual control devices exist which can be operated on display screens, e.g., buttons, sliders, and menu options.

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Biographical Sketch

Gunnar Johannsen is Professor of Systems Engineering and Human-Machine Systems – in the Institute for Measurement and Automation of the University of Kassel, Germany, from 1982 to 2006. Since he retired from his duties in teaching and administration in 2006, he concentrates more on research and, particularly, on scientific writing. Further, he is orchestral conductor of Vienna classical and of contemporary music since 1999.

He received his Dipl.-Ing. degree (1967) in communication and information engineering and the Dr.-Ing. degree (1971) in flight guidance and manual control 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.) at the Technical University of Aachen, Germany. From 1971 to 1982, he was division head in the Research Institute for Human Engineering 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 (1995) and the Kyoto University (1995 and 2004) in Japan, in the Technical University of Vienna, Austria (1999), also supported by the Institute of Electro-Acoustics, Experimental and Applied Music of the University of Music and Performing Arts Vienna, as well as in the University of British Columbia in Vancouver, Canada (2004).

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;

Springer, Berlin 1993). In IFAC (International Federation of Automatic Control), he founded and chaired the Working Group on Man-Machine Systems (1981–1990). He served as Chairman for four of its Symposia between 1982 and 2001. Also in 2001, he created and was main responsible of an International Workshop on Human Supervision and Control in Engineering and Music, with an embedded orchestra concert in which he conducted Takemitsu's November Steps.

He is Fellow of the IEEE (Institute of Electrical and Electronics Engineers; Systems, Man, and Cybernetics and Computer Societies) "for contributions to human-machine systems engineering, cognitive ergonomics, human-computer interface design, and human-centered automation". Further, he was recipient of a Japanese-German Research Award (granted by JSPS, the Japan Society for the Promotion of Science). In 2005, he received the title of Docteur Honoris Causa (Dr. h.c.) from the Université de Valenciennes et du Hainaut-Cambrésis in North France.

His current research interests are in human-machine systems, human-centered computing, automation, and design, cognitive systems engineering, graphical, auditory, and multimedia user interfaces, gestural control, audio and music technologies, decision support systems, knowledge engineering, usability engineering, co-operative work, and interrelations between engineering and music.

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