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Concepts of user centered automation

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Abstract The accident statistics of large technical systems have been steadily improved during the last decades. Also the number of fatal accidents in air and surface transportation is decreasing in spite off increased traffic. However, the relative share of so called human errors is increasing across application areas. Hence, for further improved reliability, the functional integration of humans in such systems must be reconsidered. Since the user, in the long run, will not and should not be eliminated by computers this paper reviews basic requirements of a human centered automation. Following an analysis of generic system functions, human factors requirements for automated functions are defined. It is shown how manual functions can be supported by assistance functions, for which a general system architecture and a classification scheme are presented. © 2001 Éditions scientifiques et médicales Elsevier SAS

Zusammenfassung Die Unfallstatistiken großtechnischer Systeme haben sich in den letzten Jahrzehnten ständig verbessert, auch die Anzahl der Unfälle mit Todesfolge im Luft- und Straßenverkehr sinkt bei wachsendem Verkehrsaufkommen stetig. Der relative Anteil sogenannter menschlicher Fehler nimmt dagegen in allen Bereichen zu. Es besteht somit Anlaß, die Rolle des Menschen in derartigen Systemen neu zu überdenken, um die Zuverlässigkeit komplexer Systeme weiter zu erhöhen. Da der Benutzer auf lange Sicht nicht durch Rechner eliminiert werden kann und soll, untersucht dieser Beitrag die Erfordernisse einer benutzergerechten Automatisierung. Nach einer einleitenden Analyse grundlegender Systemfunktionen, der Automatisierungsgrenzen und der Leistungsdefizite des Menschen werden mögliche Formen und Strategien der Funktionsteilung zwischen Automatik und Benutzer hergeleitet. Zur Unterstützung manueller Funktionen bietet sich der Einsatz von Assistenzfunktionen an, für die eine allgemeine Systemarchitektur und ein Klassifikationsschema vorgestellt wird. © 2001 Éditions scientifiques et médicales Elsevier SAS

1. Introduction

Today, co-operation of humans and technology is a matter of course in nearly all situations of life. Some areas of application for man-machine systems are:

- Process control of industrial plants:
  - traffic control;
  - power production;
  - communication.
- Navigation and control in transportation:
  - motor vehicles;
  - airplanes;
  - rail-mounted vehicles;
  - ships.
- Specific technical applications in space, under water, and military.

Mostly the automation in such systems is motivated by the fact that a task can be performed cheaper, quicker, more exactly or more reliably by machines than by manual operation. Frequently it is also assumed that automation simplifies the handling of complex systems. However, due to technical limitations, not all required

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functions can be automated. Especially difficult subtasks remain for manual operation [1,2,4].

The removal of subtasks from a work routine truncates the normal working procedures. Users find it difficult to cope with the task segments, which remain for manual operation. Wiener and Curry comment on this problem: “The question is not whether a function can be automated, but more whether it should, due to various human factors questions that are raised” [11].

2. Functions in complex human-machine systems

In complex, hierarchically structured systems, the functions indicated in *figure 1* occur.

Communication consists of the establishment of communication links as well as in sending and receiving messages. Communication with the external world concerns the receipt of requirements and boundary conditions from superior or concurrent processes. Based on this information, the mission to be accomplished is identified. Messages concerning the actual system state may be passed on. Local communication concerns the verbal information exchange among crew members.

Correct situation assessment is a crucial prerequisite for system control. To this end users observe the environment directly or indirectly by displays of sensor data. The estimation, whether all necessary and relevant symptoms for a correct situation assessment are available, is just as difficult for humans as the identification of the actual situations.

Planning is a multistage process, that selects from a number of possibilities of actions the one that leads to the desired goal. The task of planning consists of finding ways from a determined starting situation over intermediate steps to a target state. Set values are handed over to the guidance level.

Guidance is performed by comparing a plan with the actual situation. Hence deviations can be identified

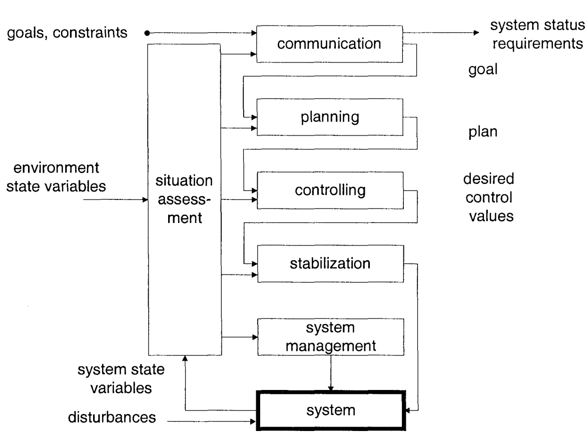

Figure 1. Functions in complex systems.

and compensated. During stabilization high frequency deviations from the set values are compensated.

System management has to address two different aspects. ‘Resource management’ is concerned with the use and the supply of subsystems (e.g. switching on or off autopilots or the reconfiguration of subsystems). ‘Error management’ guarantees the operating ability by function replacement (technical redundancy), possibly followed by error compensation and repair. Error management can also consist of the transfer of a defective system to a safe fall back level (e.g. switching off a power station).

3. Concepts for man-machine function allocation

In automated systems, tasks are shared among humans and automata. There are serial and parallel concepts how both contributions can be interlaced in order to achieve a common goal [3,9].

In a serial organization humans and technical systems complement each other by performing successively different subfunctions (*figure 2(a)*). In the non-redundant parallel organization humans and computers perform ‘different’ functions at the same time (*figure 2(b)*).

In the redundant-parallel concept humans and computers work on the ‘same’ task simultaneously (*figure 2(c)*). In this case the computer provides an assistant function.

The different function allocation concepts depicted in *figure 2* may be classified according to operation research terms, where a distinction is made between line and staff functions. Line functions are entitled to decide, while staff functions have only advisory and decision-preparing tasks. Thus automated functions as shown in *figure 2(a)* and *figure 2(b)* correspond to line functions, because they act autonomously without intervention of an operator. In contrast *figure 2(c)* shows the computer in a staff function.

As shown, the use of computers in man-machine systems can take the form of an automaton or of an assistant. *Figure 3* depicts a schematic system architecture, which considers both concepts.

3.1. Realization concepts for automatic functions

The architecture of a man-machine system with permanent and on/off automatic functions is shown in *figure 4*. Permanent automatic functions usually perform tasks which are not suited for manual control such as, e.g., stabilization of high frequency disturbances.

On/off automata cover the range of the optionally activated functions (e.g. autopilots). The activation follows different strategies:

– management by delegation (autonomous operation, if switched on);
– management by consent (autonomous operation following acknowledgement by the operator);

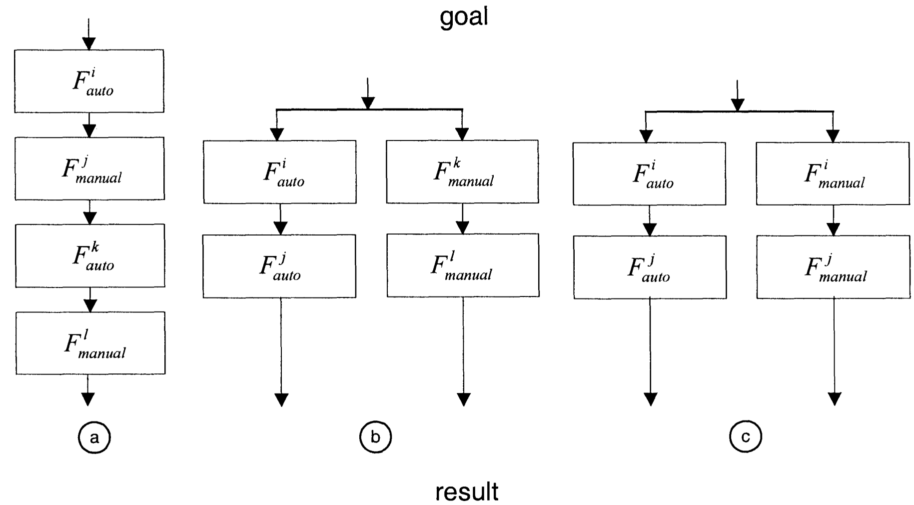

Figure 2. Concepts of function allocation between man and machine: (a) serial; (b) parallel; (c) redundant-parallel.

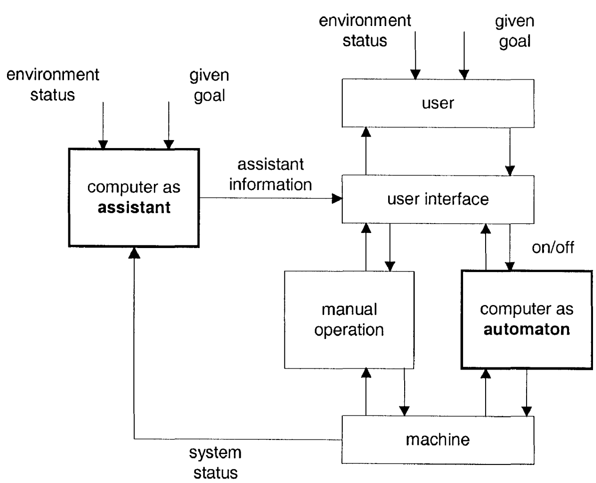

Figure 3. Computer as automaton and as assistant in a man-machine system.

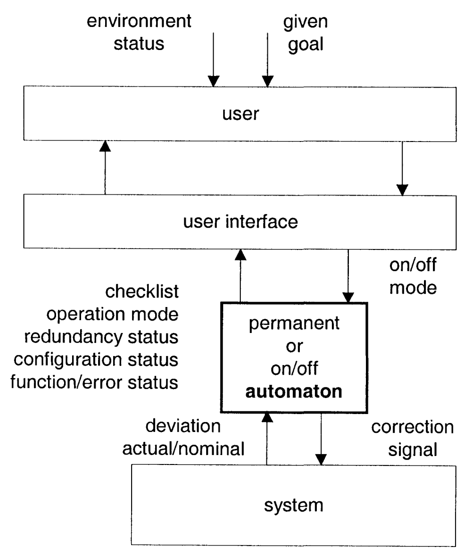

Figure 4. Permanent and on/off automata in man-machine systems.

– management by exception (autonomous operation, optional check by the operator).

For the choice of one of the handover strategies mentioned above the workload of the operator and the possible consequences of a malfunction are decisive. Dangerous actions should not be delegated to autonomous operation, since unexpected software and logic errors may occur at any time.

Generally, it has to be noted, that any auto-mode operation puts an operator into an out-of-the-loop situation. As a consequence the training level of an operator deteriorates during automated operation, due to lack of active action (*figure 5*).

Therefore breaks between manual phases of operation must not be too long. The training level must be kept so high that in the case of loss of the automated function a manual takeover remains feasible at any time without loss of performance.

Work in automated environments requires continuously high concentration and attention for a monitoring task, particularly during long-term operation. Investigations show that operators have difficulties in concentrating on one task over long time periods. Therefore technical measures have been developed in order to determine the current level of attention of an operator, e.g.:

– periodic inquiry of forced reactions;
– presentation of synthetic alarms.

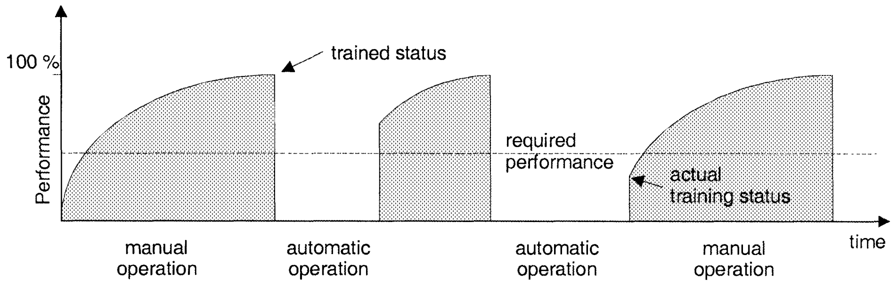

Figure 5. Intermittent manual operation for maintenance of training level.

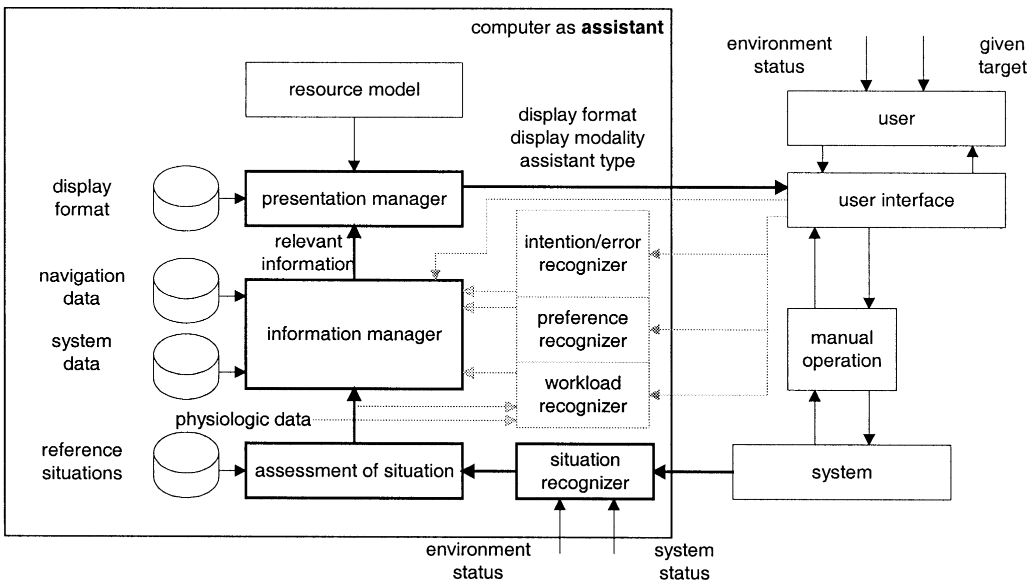

Figure 6. General system architecture of an assistant computer.

An automatic system should be transparent which means that operators must be able to understand their functions. This refers to intact functions and even more to the understanding of malfunctions. Since errors can be judged only as deviation from a known baseline normal, nominal behaviour has to correspond to the expectations of an operator. Therefore automatic functions should:

– work similarly to manual operation;
– be comprehensible;
– be predictable.

The transparency of an automatic system is enhanced if the following information is provided to the operator:

– checklists;
– status of operating modes;
– redundancy status;
– configuration status;
– function/error status.

Any failure should produce a message (no fail-passive). Warnings must be clear and reliable, and the rate of false alarms has to be small. If derived information is used, the raw data should be accessible for examination.

3.2. Realization concepts for assistant functions

A general architecture of an assistant computer, which considers concepts of different authors, is shown in *figure 6* [1,5,7].

Key component of the architecture is the ‘automatic situation assessment unit’ which registers the system status based on sensor data. This is followed by an ‘information manager’ that filters the available information in such a way that the operator receives only the information he needs to know at a particular time. An ‘intention and error recognizer’ then logs the control inputs of a user and tries to associate them with normative procedure segments from the system database. According to a pre-determined agreement this permits the conclusion on the targets pursued by the user. In case of deviations it is

Table I. Assignment of assistant types to airplane functions.

Ass.-Type function	Information	Advising	Commanding	Intervening
Stabilization			Flight vector displays Stickskakers, Callouts	Manoeuver limiters Quickening
Guidance			Ground Proximity Warning System (GPWS)	
Planning	Flight Management System (FMS)			
Management		Electronically Centralized Aircraft Monitoring System (ECAM)		

possible to infer changed objectives (e.g. change of the airway, over a thunderstorm) or errors [6,8,12].

The ‘preference recognizer’ identifies individually preferred behavior and generates suitable assistant information. A ‘workload recognizer’ tries to estimate the current workload of a user by analyzing speed, accuracy and errors of operator actions. In addition a ‘presentation manager’ controls the information on the user interface. The display format database provides available display formats.

The choice of the sensory modality for the information presentation is determined by the actually available load of the sensory resources and from the modality of the requested reaction. Overloading of a resource requires code conversion of information into other modalities according to the theory of multiple resources [10].

Apart from format and modality, the contents of assistant information can also be adapted to the requirements of a certain situation or task. To this end four different assistant types can be distinguished, which are labeled:
– informing assistants;
– advising assistants;
– commanding assistants;
– intervening assistants.

‘Informing assistants’ make use of a database integrated in the system, which the user accesses as required. ‘Advising assistants’ make use of an expert system in connection with an automatic situation recognizer. Thus a situation-adapted consultation becomes possible. ‘Commanding assistants’ are applied in work situations, which are characterized by extreme time pressure. The available assistance consists of situation-dependent visual, acoustic or haptic commands, which can be obeyed or ignored. Finally ‘intervening assistants’ cause a situation-dependent limitation of user inputs, which are brought to the attention of the user usually by haptic stimuli. In some systems the set constraints can be manually overridden.

Table I shows some examples to clarify the assignment of assistant types to planning, guidance, stabilization, and management functions in airplanes. Planning is supported by the Flight Management Systems (FMS). The FMS is an information type assistance system which provides information to the pilot on request.

In contrast the ECAM system (Electronically Centralized Aircraft Monitoring) is an actively advising assistance system that supports the management of system resources and error handling. The error messages given are adapted to the actual flight phase. Furthermore a message prioritization hierarchy prevents a message overload.

An example for a commanding assistance is the Ground Proximity Warning System (GPWS) on the guidance level. It generates warning commands if the distance to ground is critically low. Another example of haptic commanding assistance is the stickshaker which causes the control column to shake in case of an impending stall. Assistance systems of the intervening type may be observed on the stabilization level. Among these are manoeuver limiters or special display modes like quickening.

4. Summary

The control of increasingly complex systems is possible only by the use of computers. Since in many cases full automation is neither feasible nor reasonable, function allocation between humans and automation is critical.

In this contribution basic system functions were outlined. For the automated system functions requirements were defined regarding transparency and feedback. For manual operation the use of assistant functions was suggested and a general architecture of assisting systems was presented. A classification was proposed that distinguishes informing, advising, commanding and intervening assistant functions.

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