Visualization and Man-Machine Interaction in Clinical Monitoring Tasks

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ABSTRACT
The user interface of current monitoring equipment is often inadequate for a clinician's routine tasks. An improved ergonomic design of the user interface requires the consideration of human factors aspects that will be discussed. Based on a model of the anesthesiologist's monitoring task the user interface design of an anesthesia decision support system will be described as an example. The essential aspects of this user interface comprise appropriate information structure, information coding by color and shape, user guidance, and interaction via a touch input facility.

1. INTRODUCTION
The physician is expected to make a diagnosis and to follow up the outcome of his therapeutic actions. The quality of this task is based on a comprehensive set of measurements (physiological and engineering aspects) and data processing (computer science aspects). However, these results are conventionally displayed in a way which is inadequate for a clinician during his routine work. Therefore, an appropriate ergonomic design is indispensable, the more complex the systems become [8]. Part of the ergonomic approach is the design of visualization and interactivity.

Experience, specifically in clinical monitoring, was acquired in our studies designing a highly interactive user interface for the 'Anesthesia Information System' (AIS) [1]. Now we are applying and extending this experience in the design of a user interface for a knowledge-based decision support system (AES-2) [9] connected to AIS. The purpose of AES-2 is to assist the anesthesiologist during a surgical operation in assessing the patient's state and in deciding on therapeutic actions.

2. COGNITIVE ASPECTS IN MONITORING
Optimal behavior in monitoring is reduced by human limitations of the perceptual, memory, cognitive, and motor systems [6]. In diagnosis for example, it creates a heavy workload for short-term memory to bear several data items in mind in order to interpret them at any time with respect to correlated rules. In critical situations the operator tends to consider only a few variables, ignoring other relevant information ('cognitive tunnel vision'). In finding an explanation for the actual state, he tends to adopt the first solution without searching for alternatives ('tendency to stick with a decision') [6].

During the design of a monitoring device based on ergonomic considerations these problems are addressed with comprehensive but also efficient information coding and presentation that properly support each phase of the user's task.

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The concept of knowledge-based systems (KBS), evolving from the research area of artificial intelligence, offers new possibilities of supporting the physician in his monitoring tasks. However, acceptance of these new concepts can only be reached if the user interface of the KBS is designed applying human factors principles [5].

The following paper is essentially focussed on discussing user interface aspects of the anesthesia decision support system AES-2 and on its proper integration in the overall monitoring task.

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3. SYSTEM INTEGRATION AND INTERACTION

During complicated surgery the anesthesiologist has little time to spare for interaction with the computer, a fact which generates one major problem in the design of a knowledge-based system for intraoperative use. Consequently, AES-2 is designed as an integral component of an advanced, highly interactive anesthesia information system (AIS) [1] that assembles the information required for operation monitoring and documentation (Fig. 2). Instead of prompting the anesthesiologist for information (consultation mode), AES-2 operates on-line in a monitoring mode and bases its conclusions solely on the information made available by the AIS; distinct from conventional expert system concepts, it does not request any additional inputs from the anesthesiologist. But if desired, interaction is possible to question the system’s recommendations or to review special information sources.

Fig. 1: Proposed model of the anesthesiologist’s task. From [4].

Fig. 2: Integration of Knowledge-Based Decision Support (AES-2) in the Anesthesia Information System (AIS). From [2].

In our approach, ‘direct manipulation’ operations are used to provide easy and faultless interaction both with AIS and AES-2. Entries into AIS or control actions for AES-2 are performed by directly touching virtual function keys on the high resolution color display that elicit immediate responses. Analogous data can be input by virtual ‘sliders’ using the finger touch input mode. User guidance is achieved by marking areas sensitive for touch input with a special color.

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4. KNOWLEDGE BASE STRUCTURE: STATE VARIABLE MODEL

Based on investigations of the lines of reasoning that underlie the decisions of experienced anesthesiologists, a hierarchical structure of all data ('state variable model') was developed for structuring the knowledge base. The overall state of the patient depends on the states of several subsystems such as hemodynamic, fluid balance, blood gas analysis or electrolyte balance. Each of these subsystems is described by several 'state variables'; e.g., state variables such as 'myocardial contractility', 'vascular tone' or 'blood volume' are the basic concepts for evaluating the subsystem 'hemodynamic'.

These state variables reflect the physiologic and pathophysiologic state of the patient. The values of most state variables cannot be measured directly; they can only be estimated as a complex combination of measurable signal values, patient data and patient reactions to previous therapeutic actions. Correction and maintenance of these state variables within a 'normal' range that depends on the type and phase of the operation is the principal goal of the anesthesiologist; so monitoring of state variables becomes a major task in assessing the patient's state. Therapy recommendations are the results of a hierarchical process of dynamic replanning, utilization of knowledge about drug properties and default action schemes combined with results of previous medications [9].

5. DISPLAY STRUCTURE

In complex systems the total information must be structured and presented sectionally in order not to overload the visual system. In our approach the steps of Fig. 1 are translated into several non-overlapping windows. These windows are either permanently visible or can change their state between being 'visible' and being replaced by an 'icon'. The screen layout contains the following windows:

- results of the continuous evaluation of the patient's state variables ('state variable window')
- current values of vital parameters
- preoperative patient data
- therapy plans in relation to a selected state variable: suitable drug and recommended dose
- schedule of administered drugs and infusions
- information about routine tasks.

The provided functions for user input include (1) requesting a recommendation of an appropriate therapy plan, (2) changing the recommended dose of a drug or (3) opening/closing nonpermanent windows. In this way the information display is controlled by the user and can be continuously adapted to the actual situation. Only the evaluation of state variables and information about routine tasks are permanently visible, since these items are essential for the patient's safety.

6. VISUAL INFORMATION CODING

An acknowledged model of human information processing [11] proposes a high-capacity, parallel-processing mode (visual, holistic) and a low-capacity, serial-processing mode (verbal, analytic). Therefore, information coding suited for parallel processing provides for rapid information extraction from the display. Visual information can be prepared for holistic assessment by use of e.g. icons, color coded alarms, or shapes, which are suitable for easy recognition; this supports the idea of 'catching the situation at a glance'. Judgement of the state of a system may be based on pattern recognition [7].

In the following, one window essential for patient monitoring is discussed as an example for the described principle (Fig. 3). It displays information related to the evaluation of the state variables. These state variables are represented by appropriate icons developed in cooperation with anesthesiologists. The icons in Fig. 3 represent 'myocardial contractility', 'heart rate', 'vascular tone', 'narcotic level' and 'blood volume'. In a rectangular field beside each icon the result of the evaluation is redundantly coded by color and shape. Bars to the left side of the center line indicate a state 'below normal'. Increasing deviations from 'normal' are indicated by increasing length and 'redness' of this bar. A state 'above normal' is coded in the same way with colored bars to the right side. The arrangement of these bars below each other in a block forms a vertical profile, a pattern representing very condensedly the actual patient state.
On the right side trend-keys indicate the actual course of the evaluation of state variables. It is also used as a virtual key to change the depiction in the rectangular field to a graph displaying the course of time of earlier evaluation values.

Since the information in the state variable window is essential to the anesthesiologist, it is permanently displayed. The user himself can open or hide additional windows, as it is required in order to access an explanation facility. Thus, the amount of displayed information is adapted to the user's needs. Only windows relevant to the actual task are visible, thereby reducing the workload on the user's visual system.

CEDI provides the use of three color spaces: the well known RGB color space, the more intuitive understandable HSV color space and the perceptually uniform CIELAB color space. Each color space has certain advantages, dependent on the context in a color selection problem. Direct manipulation by mouse input is used to adjust a color in one of the three color spaces. In addition, CEDI enables interactive color modification directly in the displayed application layout by using a second screen that is connected to the application.

8. PERSPECTIVES

The user interface design of complex systems requires appropriate prototyping methods to meet the user's needs. The design of the anesthesia information system AIS and of the knowledge-based decision support component AES-2 has helped us to acquire considerable experience applying rapid prototyping methods and to determine the requirements for tools that can support the design process [4]. The development of the above described color editor CEDI is an example of this work. We are currently developing an approach for a comprehensive user interface management system. This system facilitates the integration of appropriate tools for supporting both the construction and the evaluation of a user interface. This is in particular important for the design of multimodal user interfaces, i.e., user interfaces that combine several interaction techniques, for example mouse, touch input, speech input and output, etc.
REFERENCES