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Introduction of knowledge bases in patient's data management system: role of the user interface *

M.C. Chambrin,[1] P. Ravaux,[1,2] A. Jaborska,[2] C. Beugnet,[2] P. Lestavel,[3] C. Chopin[1,3] & M. Boniface[2]
[1] *INSERM U279;* [2] *Lab. Biomathématiques, and* [3] *Service de Réanimation Polyvalente, HOP B, Université de Lille II, France*

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Abstract

As the number of signals and data to be handled grows in intensive care unit, it is necessary to design more powerful computing systems that integrate and summarize all this information. The manual input of data as e.g. clinical signs and drug prescription and the synthetic representation of these data requires an ever more sophisticated user interface. The introduction of knowledge bases in the data management allows to conceive contextual interfaces.

The objective of this paper is to show the importance of the design of the user interface, in the daily use of clinical information system. Then we describe a methodology that uses the man-machine interaction to capture the clinician knowledge during the clinical practice. The different steps are the audit of the user's actions, the elaboration of statistic models allowing the definition of new knowledge, and the validation that is performed before complete integration. A part of this knowledge can be used to improve the user interface. Finally, we describe the implementation of these concepts on a UNIX platform using OSF/MOTIF graphical interface.

Introduction

In intensive care area, increasingly data are available to the clinician through monitoring systems and laboratory tests. Currently, if we only consider the data coming from monitoring systems which can be automatically acquired, on the basis of an hourly routine measurement, more than six hundred data items a day per patient, have to be treated by the clinician. Then, other clinical data and images must be added to this large amount of data. The management of these different types of data requires the design of adequate means for automatic and manual acquisition. Development of knowledge based system is one way to improve the management, the representation and the interpretation of these data. Often, published papers present interesting solution related to the interpretation of the data, but most of them have a limited focus with poor attention related to the user interface.

According to our own experience and recent review in the literature [1, 2], clearly, the user interface seems to be the key problem, considering end user's acceptance of any system. In this paper, at first we present the methods we have used to build a friendly user interface based on clinical requirements. Thereafter, we describe the methodology developed to utilize the user interface, as a mean to acquire new knowledge about clinical practice. Eventually, our plans to further improve the ergonomics of the user interface are explained.

State of the art

The commercially available systems (e.g. by Emtek, Hewlett-Packard, Marquette, Spacelabs) for patient data management, called clinical information system, have been conceived to replace the daily care flow-

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sheets by computerized sheets. They mainly use tabular format for data presentation. Advantages of such systems, including improvement in data collection and quality of documentation have been discussed [3, 4]. However, the high cost of such systems compared to their potential benefit have limited their diffusion. Still, they do not exploit the possibilities given by new technologies regarding the design of user interface. Typically, graphic object to synthetize the information as well as multimedia facilities (medical imaging, sound), have not been utilized.

In parallel, at research level a lot of work is performed to develop knowledge-based systems. As required knowledge in intensive therapy is very large, they usually have their focus on a specific area [5–8]. These knowledge systems are not yet sophisticated enough to provide pertinent information for the physician.

For the clinician, it is a quite simple information to know that the patient is stable. However, this requires a synthesis of many scattered variables and may take time. The analysis of all the needed information can be realized quite easily by microcomputer to be continuously available for the clinician. This information is called knowledge, basic level knowledge, in opposite to deep knowledge leading to diagnosis. In reality, systems that assist clinician in making an assessment of monitored data may be of more utility than systems that attempt to make a diagnosis.

Importance of the user interface

The use of the standardized graphic objects as defined in windowing system (e.g. widgets, gadgets of X-Window) and the respect of rules for uniformity is the first way in the design of user interface [9, 10] for a better synthesis of the whole information. We have used this principle to simplify the access to the available information for the medical staff.

In addition to the respect of the standards related to the data display, another way to improve the user interface is to integrate specific knowledge bases. This approach is based on a work performed during an European project [11], where emphasis was given to the study of user requirements and the definition of specifications.

Two parts must be considered: one is related to the design of the modules related to manual input e.g. drug prescription which are essentially user-initiated. That part is described later. The other one is related to the synthesis of the information that is essentially data-initiated. It is based on the following: according to discussion with clinical board it was found that physicians evaluate patient's state on the basis of physiological subsystems (e.g. cardiovascular, respiratory, renal). When a problem occurs, what is helpful for medical staff is to have immediately available all the appropriate data to perform his diagnosis. To achieve an initial efficiency system, we have to know in preselected cases the process of decision making.

From the stored data, the system must be able to recognize the current patient's status to present the pertinent information to the physician. The process requires initial knowledge bases at two levels: one is for the evaluation of patient's state including intelligent alarms and the other is for the representation of the relationships of cause and effect. This last aspect is what we define as 'to present the data in a contextual fashion'.

For example, in case of an alarm raised because of failure of CO_2 sensor, a simple alarm dialog box containing textual message is not sufficient. This mode of presentation of the conclusion does not include any knowledge. It is a limited and static view of the need of the physician for an efficiency help. It does not support the entire decision making process. In fact, taking into account this information, the clinician reacts to make a decision based on information that can be capture through the user interface.

To detect an alarm is correct but not sufficient reaction of a user. Once the site of the alarm is located by the clinician, depending on the problem, different kind of information can be useful. The representation of these parameters using trends or histograms, corresponding to his need may improve the interpretation of this alarm. It is this mechanism that must be integrated into knowledge bases.

For the previous example, we have tried to develop a module that synthetizes the information. This module anticipates the needs of the clinician for:

- A complete understanding of the alarm by a schematization of the patient-ventilator system flashing the faulty sensor, displaying a small dialog box with short textual explanation and displaying also the data that have been used to detect this failure.
- A better understanding of the consequence of the sensor failure in the computation of different values.

Data or parameters that are affected by this failure are presented simultaneously. In the trend representation of these parameters, the use of a specific color related to sensor failure may be helpful when the clinician reviews the data.

The medical way of thinking is complex and difficult to be intercept by the knowledge engineer. Because it is quite instinctive for medical staff, it is not easy to express by the clinician and may then not be perceived by the knowledge engineer.

Conception and design of the user interface

We have the opportunity to work in close collaboration with clinicians and nurses. Before the development of the prototype, analysis of the methods of work of clinical staff was regarded (based on observations and interviews). In fact, what clinicians say is not what they do. Besides, there is no uniformity in the means used to access to the data.

That kind of development procedure requires a lot of time, but leads to software module which may be used very naturally by medical staff.

To develop a user friendly interface four steps are used:

1. During meeting with medical staff, we demonstrate different widgets that may be useful to manage their acts in the clinical environment.
2. Models are built using powerful graphic tools on a small microcomputer (Supercard on Macintosh). This model runs in the same way that the future interface, except more slowly.
3. Clinical staff tests this demonstration model. It must reflect the dynamics of the user interface, but it must not be a manual train of static screens. The dynamic aspect must be taken into account since the beginning of the study. We use the classic 'trial and error' approach to improve the current interface.
4. User interface modules are then implemented on the target system. This step requires a lot of time in development, because we used tools to ensure the maximum portability. When implemented, the software is tested by the end users, before its use in the clinical environment. Modifications, if needed, are made in the target system.

This classic procedure is very efficient for the constitution of the modules that require manual data input but not for modules for the presentation of the information. That aspect is more data-driven than user-driven. To improve this, we have integrated in our conception a mechanisms that will allow to apprehend the medical practice through the user interface. It is a way to capture new knowledge, keeping in mind that it is not fundamental knowledge, but knowledge integrated in clinical practice.

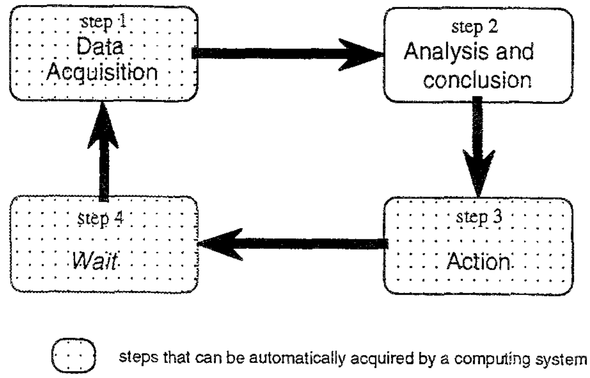

Fig. 1. The four steps of the decision process.

Evolution of the user interface. Automatic constitution of new knowledge bases

Architecture of the system is built to allow the evolution of the knowledge bases. This evolution is dependent on the spontaneous, intensive and natural use of the user interface. That is why the initial conception of this user interface is crucial to obtain the best interaction between the system and the user.

The method is based on the following model that is not specific to the medical area. It corresponds to the decision process making of any expert.

In a first step, the expert acquires all the available data, including physiological data, clinical signs, biological results, images. This step is realized more or less easily by a computing system, depending on the nature of the data. Then the process of cognition of the expert comes into action to take decisions. This part is difficult to apprehend and must be improved in the future. The third step corresponds to the realization of the decision by making action. In medical area this corresponds to new drugs or new therapy (like ventilatory support, renal support). To take into account the response time of the physiological system related to the last action, we have introduced in the model a delay between the last action and the next acquisition. Thus, decision process is cyclic (Fig. 1).

We have tried to implement this model in the computer system using the user interface as the only mean of interaction.

The system scans continuously events sent or received through the automatic data acquisition modules and the user interface. Simultaneously, all user's actions through the user interface are stored. Using statistical methods it will be then possible to retrieve the intellectual process of the medical staff in clinical practice.

For example, a new knowledge determined by the system could be:

'If the patient is in the S1 state, then the clinician will require the display of ventilatory parameters and the X-ray pulmonary images and the blood gas results, finally he may modify the settings of the ventilator.'

In fact, the user interface is able to construct and display this knowledge because, at any time, it manages all the data reflecting the patient's state. When this linking of actions and decisions has been labelled with a representative statistical number, a new knowledge is created.

In concrete terms, an action can be:

- a request for displaying parameters. When a screen is displayed, it is not possible to know which is the parameter really used by the clinician. So, we take into account all the parameters visualized on the current screen. Using discriminent analysis it will be possible to recognize the pertinent parameter(s).
- a prescription (drugs or medical tests).
- a change of screen.
- a modification of a parameter before its validation.

A decision can be:

- a prescription of tests.
- a modification of the therapy.

By scrutenizing the inputs and outputs of the user interface, a global file is constructed. This file contains the sequences of actions and decisions as well as the duration (Δt) between the elements of the sequence:

ACTION1, Δt1, ACTION2, Δt2, ACTION3, . . ., Δti, DECISION1

In some circumstances, a decision may become an action and a new sequence is created.

The first step of the study is to use an enumeration method to answer to the following question: what is the probability to have the DECISION$_i$ if the sequence SEQ$_i$ is present? When this probability will have reached a 'sufficient' threshold, the system would be able to propose to a junior the most frequent decision when the sequence will have been recognized.

A second step will consist of the establishment of statistical models using a classical method of discriminant analysis. From this analysis, it is possible to build

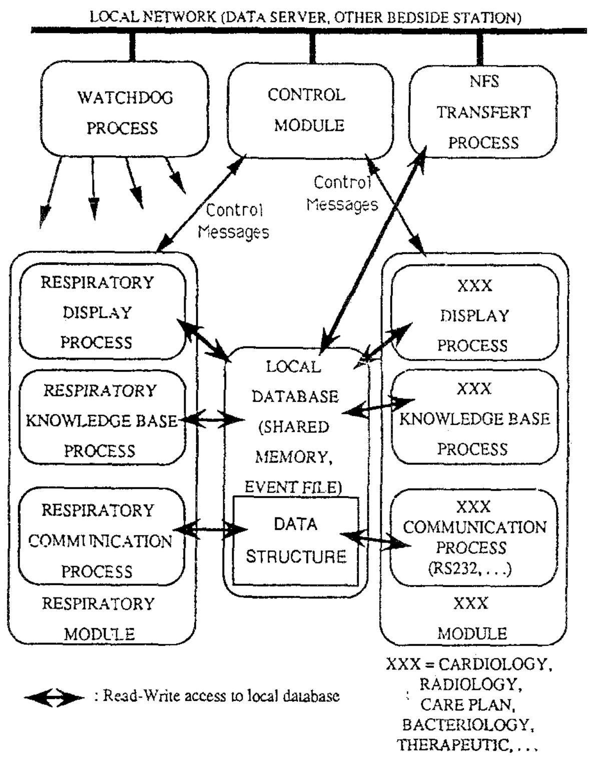

Fig. 2. Software architecture of AIDDIAG prototype.

rules that will be submit to the clinician to obtain medical explanation. Then these rules will be introduced in the system for validation. The phase of validation consists of comparing this new sequence with the real use of the system during its running. If the similarity is valid this new sequence is a new knowledge integrated in the system. This approach allows to be free from the traditional methods used by the knowledge engineer like interviews. We have started to implemented this structure on a bedside workstation.

Implementation

All these concepts have been used to implement a prototype system, running under UNIX operating system. This prototype is composed of independent modules (Fig. 2) that each represent a physiological function. These modules exchange information using shared data (shared memory for quick access, NFS for other information) or messages (X-WINDOW events or FIFO).

Currently, the prototype includes a module for the respiratory function, one for cardiac function and one for drug prescription and laboratory data.

A specific module has been developed to manage medical pictures, as X-ray, scanner or IRM pictures. So, the clinician can have a maximum of information about the patient's status on the bedside workstation display.

The same internal structure has been used for each module. They are composed of three processes, respectively dedicated to automatic data acquisition, user interface and knowledge base management. The first process acquires data from medical monitors with a sampling rate of 0.2 Hertz. It then filters these data before writing in the shared memory. With this data acquisition frequency, it can also detect low level alarms (disconnection, data inconsistencies) and send them to user interface process. The user interface process reads the data existing in shared memory, receives messages from other modules, and displays them in a graphical and easily interpretable format. The third process, using specific knowledge bases for the assessment of the physiological function associated with this module, reads facts from the shared memory (coming from the first process, for instance), produces conclusions and then writes them in the shared memory.

All these processes are running independently and asynchronously. The use of a shared memory allows short response delay, in spite of the numerous processes.

The display processes use the X-WINDOW 11 functionalities with OSF/Motif graphical interface. This allows us to use X11 network facilities without new development. So, all these processes can be displayed on a remote computer (Apple Macintosh, PC under MS-DOS, . . .).

This prototype is now running on IBM RS/6000 workstation under AIX operating system (UNIX-like OS).

For legal reasons, we are developing a specific security model. The problem is to control the different access rights of the data for many different medical staff members, without overloading the user interface. A solution is under development, using touch-screen and personal pens.

All the mechanisms of scrutenizing have been implemented and tested on short data collection.

Conclusion

It is more and more admitted that the user interface is the key point for user acceptance of any clinical information or intelligent monitoring system. We have tried to demonstrate that the user interface can be also a mean to acquire new knowledge. This knowledge can be used at different levels:

- to improve the current user interface according to the clinical practice
- to improve patients monitoring. The construction of a platform, able to acquire the maximum of data available in intensive care environment, allows to consider the implementation of learning methods for: recognition of complications, determination of pertinent and forewarning parameters related to these complications.

The model we have used is transposable to other non medical domains where the monitoring of complex systems is required. Problem of such approach is that it has required a lot of time in development. But, the work in collaboration with the end user is the only mean to be sure that the information displayed at a given time is the pertinent and helpful information related to the current state of the patient or the process to be monitored.

The tools that has been chosen for development, in particular X-Window, UNIX and C, allow an evolution of the current platform towards the new generation of multiprocessors and distributed systems without any significant modification of the software.

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References

1. Mora FA, Passariello G, Carrault G, Le Pinchon JP. Intelligent patient monitoring and management systems: a review. IEEE Engineering in Medicine and Biology 1993; 12(4): 23–33.
2. Thull B, Popp HJ, Rau G. Man-machine interaction in critical care settings. IEEE Engineering in Medicine and Biology 1993; 12(4): 42–9.
3. Kari A, Ruokonen E, Takala J. Comparison of acceptance and performance of automated and manual data management systems in intensive care. Int J Clin Mon Comput 1990; 7: 157–62.
4. Hammond J, Johnson HM, Varas R, Ward CG. A qualitative comparison of paper flowsheets vs a computer based clinical information system. Chest 1991; 99: 155–7.
5. Uckun S, Dawant BM, Lindstrom. Model-based diagnosis in intensive therapy: the YAQ approach. Artificial Intelligence in Medicine 1993; 5: 31–48.
6. Hayes-Roth B, Washington R, Ash D, Hewett R, Collinot A, Vina A, Seiver. Guardian: a prototype intelligent agent for intensive care monitoring. Artificial Intelligence in Medicine 1992; 4: 165–85.
7. Windyga P, Almeida D, Passariello G, Mora-Ciangherotti FA, Coatrieux JL. Knowledge-based approach to the management of serious arrhythmia in the CCU. Med & Biol Eng & Comput 1991; 29: 254–60.
8. Jamieson PW. A model for diagnosing and explaining multiple disorders. Comput and Biomed research 1991; 24: 307–21.
9. User's Guide, OSF/MOTIF^{TM} Guides, ed. Prentice Hall 1990.
10. Style Guide, OSF/MOTIF^{TM} Guides, ed. Prentice Hall 1991.
11. Hunter J, Chambrin MC, Collinson P, Hedlund A, Groth T, Kalli S, Kari A, Lenoudias G, Ravaux P, Ross D, Salle JM, Sukuvaara T, Summers R, Zaar B: INFORM: Integrated support for decisions and activities in intensive care. Int J Clin Mon Comput 1991; 8: 189–99.

Address for correspondence: M.C. Chambrin INSERM V279 1, rue du Professeur Calmette 59019 Lille Cedex, France