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Formalization approaches of ergonomic knowledge for “intelligent” design, evaluation and management of man-machine interface in process control

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Abstract. This paper aims at describing some original works relating to the formalization of ergonomic knowledge in the field of process control. For this purpose, explicit or implicit concepts, advice and methods issued from Ergonomics, Cognitive Psychology and Human Automation have been taken into account. The medium and long-term objective is to develop engineering tools using ergonomic knowledge base. The concepts and principles used by three rule-based approaches for the "intelligent" ergonomic evaluation, design and management of man-machine interface illustrate this paper.

Key words. Process control, man-machine interface, management, evaluation, design, ergonomic knowledge, engineering tools

INTRODUCTION

The design and the evaluation of man-machine interface for process control are actually subjected to a lot of researches, leading to methodologies, techniques, tools and models already operational or currently to being validated (see for instance Helander, 1988; Gilmore, Gertman and Blackman, 1989; Millot, 1990; Tendjaoui, Kolski and Millot, 1991b). Nevertheless, according to Scapin, Reynard and Pollier (1988) about Man-Machine interaction, the present ergonomic models are often too general, too informal and lack - for the greatest part - organization to be directly usable by the designers. There are difficulties to computer scientists, automatists and even to ergonomists for the ergonomic recommendation utilization. The interface's designer is not always in a position to allow the necessary time - which is often very long - to read completely a manual of recommendations. These recommendations are often very general, and they are problems of access for a beginner. Interactions between the ergonomic criteria lead to compromises that are difficult to estimate for a beginner. The ergonomic data do not always converge according to the different design criteria (use performance, learning performance, etc). So several necessities appear : (i) to collect and structure the design ergonomical principles used, (ii) to try to bring about formal solutions in the field of man-machine interaction, (iii) to integrate these formalized ergonomic solutions into the design, evaluation and management tools.

This paper aims at describing some original works relating to the formalization of ergonomic knowledge in the field of process control. For this purpose, explicit or implicit concepts, advice and methods issued from Ergonomics, Cognitive Psychology and Human Automation have been taken into account. The medium and long-term objective is to develop engineering tools using ergonomic knowledge base. Different approaches of tools will be the subject of this paper. Their realization is based on advanced tools and techniques such as : knowledge-

based systems, objects, hypermedias, graphical toolboxes and/or machine learning. The first part of this paper describes an approach of knowledge-based system for ergonomic evaluation of man-machine interface. A knowledge-based approach for ergonomic design is detailed in the second part. Finally, the last part of this paper presents a knowledge-based approach for ergonomic management of man-machine interface. Of course it is not possible (for lack of place) in this paper to describe in detail these different formalization approaches. Our main goal consists in presenting the main concepts and principles used. For more details please see the references given.

AN APPROACH TOWARDS "INTELLIGENT" ERGONOMIC EVALUATION

SYNOP is an expert system used for the static ergonomic evaluation of graphic industrial displays. This system can improve displays automatically and give advice to the designer, through production rules centralized on knowledge bases (Kolski and colleagues, 1988; Kolski, 1989; Kolski, Millot, 1991). The general structure of the system is described in the following part.

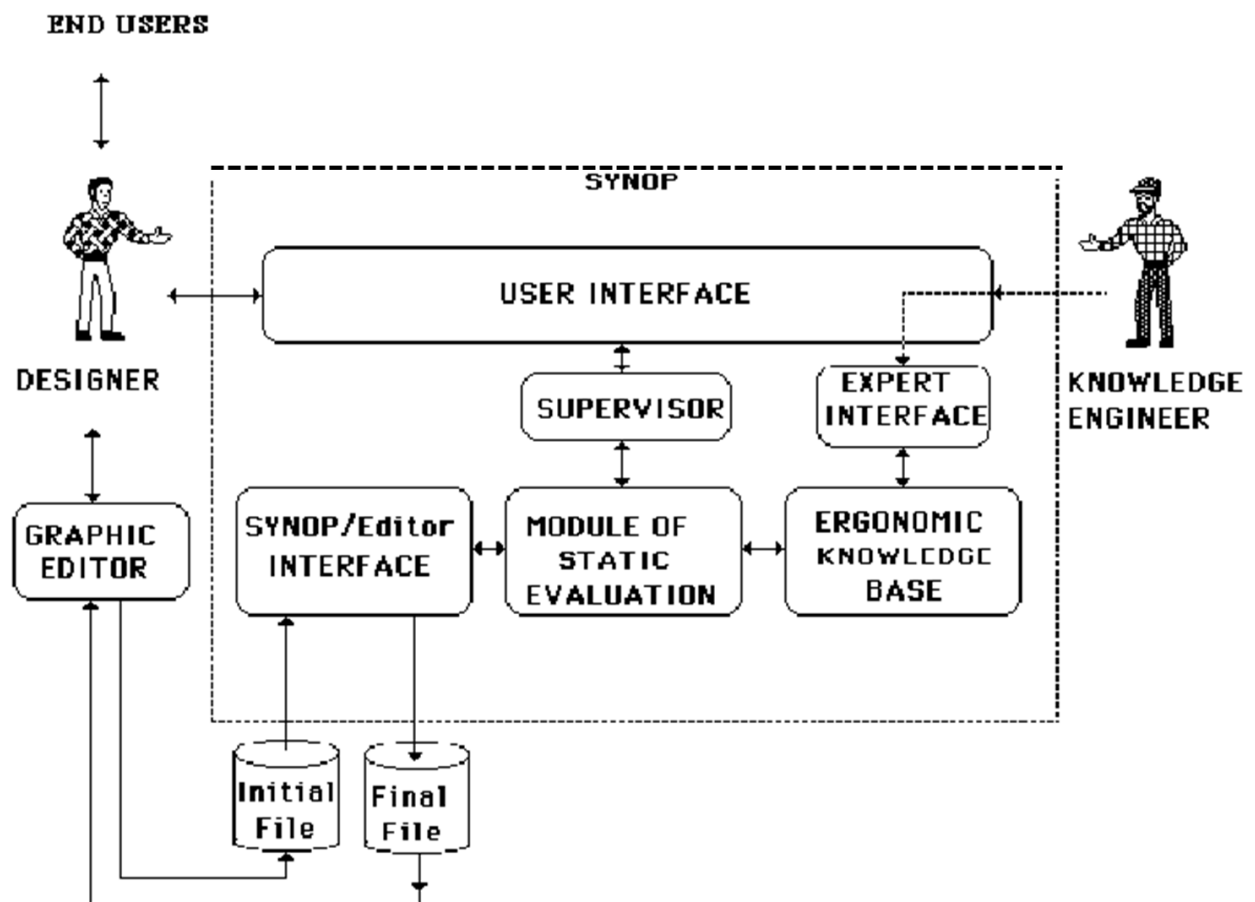


Fig. 1. Structure of the expert system SYNOP.

The Structure of the Expert System SYNOP

Developed in LISP, the system uses a first order inference engine (Grzesiak, 1987) and notions of frame (Minsky, 1975) and semantic network for knowledge representation. For the

time being, it is interfaced with a graphic editor using a G.K.S. package for creating displays. The structure of the expert system is described in figure 1.

SYNOP includes a module for the static evaluation of graphic control displays. The role of this module is to evaluate and improve the displays which have been initially created by the designer with a graphic editor, and automatically stocked into initial files. An interface between SYNOP and the graphic editor interprets these files to create a semantic network of structured objects describing the display. The ergonomic rules contained in the knowledge base are able to modify the attributes of the objects; for instance the height of a character or the colour of a curve, according to ergonomic rules concerning presentation on a graphic screen.

The improved semantic network is then reconstructed into final files by the interface between SYNOP and the graphic editor. These files correspond to an ergonomic display which can be displayed on the screen by the designer. SYNOP has two man-machine interfaces managed by a supervisor: the user interface is used by the designer to start and control the module of evaluation; the expert interface is used by the knowledge engineer to introduce and update the ergonomic rules of the knowledge base. This knowledge base is shared in "knowledge sub-bases" each related to an ergonomic theme, and into "meta-knowledge sub-bases" which contain selection criteria for the "knowledge sub-bases". The module of static ergonomic evaluation is presented below.

Module of Static Ergonomic Evaluation

Three phases define the ergonomic assessment and improvement process of a graphic display. The first phase consists in interpreting the graphic files related to the display which has been processed. This helps create a semantic network of LISP structured objects. The second phase deals with the ergonomic evaluation of the network's objects. Rules contained in the selected "sub-bases" are therefore activated to improve the presentation of the graphic display. The third and final phase helps rebuild the graphic files corresponding to the improved display. A comprehensive description of this process is given in the following part.

Initial phase of interpretation of the graphic files into a semantic network. The first phase consists in interpreting the static and dynamic graphic functions with a view to creating a semantic network of LISP structured objects describing the display. This information is created and automatically centralized by the graphic editor into binary-coded files. These files are decoded by the displays interpreter integrated into the interface between SYNOP and the graphic editor (see Fig. 1). The principle of this interpreter consists first in reading the graphic files and in transferring their content in the LISP work environment. Then, structured objects are progressively created by the instantiation of predefined LISP object prototypes for each possible type of graphic object. The structure of these objects is derived from the notion of "frames" (Minsky, 1975). Following this creation phase, links between objects are analyzed and calculated to allocate a value to the attributes of structural relations. After this phase, the objects constitute a semantic network, ready for the second phase of evaluation and improvement.

Phase of evaluation and improvement of the display. The ergonomic evaluation is carried out by inference of the rules contained in the knowledge base of SYNOP. The ergonomic knowledge is represented by production rules operated by a first order inference engine (Grzesiak, 1987). The engine is based on the sequence : definition of the set of applicable

rules, choice of a rule, inference of the rule and updating. The production rules formalism is of the following type :

IF (P1 * P2 * ...* Pn) THEN C

The condition of application of a rule is a logic arrangement of premises Pi. The operator "*" can take the value "AND" or "OR". To each premise is associated a procedure, written in LISP, which allows evaluation of the verity value by a direct test on the graphic attributes of the objects describing the display. In the same way, conclusion C is associated to a procedure which is able to improve with graphic attributes automatically. The evaluation of a display begins by a global assessment of the objects to select knowledge "sub-bases" contained in the knowledge base of SYNOP. Each of these "sub-bases" is related to the study of an ergonomic concept or theme, and contains a set of rules related to an ergonomic sub-problem. For instance, a "sub-base" concerns the ergonomic presentation of bargraphs and regroups a set of rules related to this sub-problem. Another "sub-base" can concern the legibility of characters, coloured contrasts, and so on. "Sub-rules" are selected by the activation of selection criteria, in the form of meta-rules contained in meta-knowledge "sub-bases". This method helps restrict the work space, by limiting the step of applicable rules selection to a set of effectively applicable rules. Then it helps reducing the processing time, by avoiding testing useless rules. The display is then evaluated by inference of action rules contained in each selected "sub-base". Two simple examples are presented below. The first rule allows the separation of two parallel texts, x1 and x2, from a distance equal to 100% of the height of their characters, if this distance is initially lower to this reference value. The second rule allows the change in colour of an object x1 if its color is red and if it is not in relation with the alarm notion. At present, the system contains approximatively hundred rules. These rules have been validated by experts in the field of Man-Machine Communication.

```
IF          (parallel-texts          x1 x2)
AND IF      (distance-between-then<100%-height x1 x2)
THEN (set-distance- = 100 % height x1 x2)
```

```
IF          (color-red          x1)
AND IF      (don't-represent-an-alarm x1)
THEN (change-color)          x1)
```

Modifying graphic attributes can sometimes be difficult or impossible. If so, the expert system provides the designer with general ergonomic advice concerning the processed display.

After this second phase of evaluation and improvement, the modified semantic network is coded in binary files which can be exploited by the graphic editor.

Phase of reconstruction of the graphic files related to the improved display. The third phase concerns the automatic reconstruction of the binary files issued from the expert treatment (according to the inverse principle of those described). These files can be used directly by the designer. The expert system provides the designer with more advice and explanation files which help him alter his display and also to understand the reasoning of SYNOP. These files have been progressively created during the previous phase and provide the designer with a written trace of the ergonomic process. The processing ends this phase. The designer can then

leave the software environment of SYNOP in order to improve his displays with the given advice. He can also ask for another evaluation.

Discussion

Potential interests and consequences of such an expert system are presented below with regards to the ergonomics of graphic information presentation. Four classes of applications should be considered.

Evaluation of man-machine graphic interface. In the first class, the system aims at ergonomically assisting the designer during the "static" evaluation step. SYNOP can thus help him optimize the means of presenting the graphic information, without direct help of an ergonomist. SYNOP has thus been validated during the "static" evaluation of the graphic interface between the operators and a real-time expert system. This application has taken place in the French project ALLIANCE aiming at implementing a real-time expert system for alarm filtering, diagnosis and trouble shooting (Taborin and Millot, 1986, 1988, 1989). The expert system which has been developed, currently predicts (in a continuous way) the future evolution of the process along a prediction horizon of several minutes (up to 15 min) with a prediction period of 1 min. It compares the future evolution of the process with alarm thresholds, and if need be, provides the operator with preventive advice.

Our research work concerned the development of the interface between operators and the expert system. The interface has been designed according to the operator's informational needs in the different operation modes of the process : (1) monitoring of the normal operation and fault detection; (2) problem solving and trouble shooting in the abnormal operation mode. The ergonomic evaluation by SYNOP of this interface is detailed by Kolski and colleagues (1988) and Kolski, Millot (1991). Many ergonomic improvements have been automatically made during the processing of SYNOP. The designer has thus been discharged of correction tasks, which are often dull and long lasting. Following this static evaluation, the interface has been implemented in the Cadarache power station and is being dynamically tested and evaluated with the operators.

Saving and structuration of ergonomic knowledge. The second class is related to the saving and structuring of the experts' ergonomic knowledge through an "expert" interface meant to create new ergonomic rules in the knowledge bases of the expert system. This data can be general, like the use of colours or the density of information. It can also be specific to certain applications, like process control, consultation of data bases... Such a step will help making an exhaustive list of the existing ergonomic knowledge to develop other expert system tools for interface design or evaluation. The ideal during this knowledge acquisition would be to dispense with the knowledge engineer while permitting the expert to manage himself his knowledge in the bases of the system himself. This would avoid the skew involved by the difference between the real expert knowledge and its interpretation and implementation by the knowledge engineer. Such an approach is being studied in our laboratory.

Computer-aided training in the field of graphic information presentation. The third class concerns the use of SYNOP or of such an expert tool for Computer-Aided Training in the field of graphic information presentation. This tool would assess and correct graphic displays created by the operators still training to be specialists in information presentation, or operators trying to update their knowledge. This category is directly linked to the previous category.

Such applications should be carefully considered, given the growing importance of ergonomics in interactive processing applications (Kolski and Millot, 1989).

Ergonomic design of man-machine graphic interface. The objective of the last class is to develop "intelligent" editors of industrial control displays, using rules for ergonomic design. See the second part of this paper concerning a tool called ERGO-CONCEPTOR.

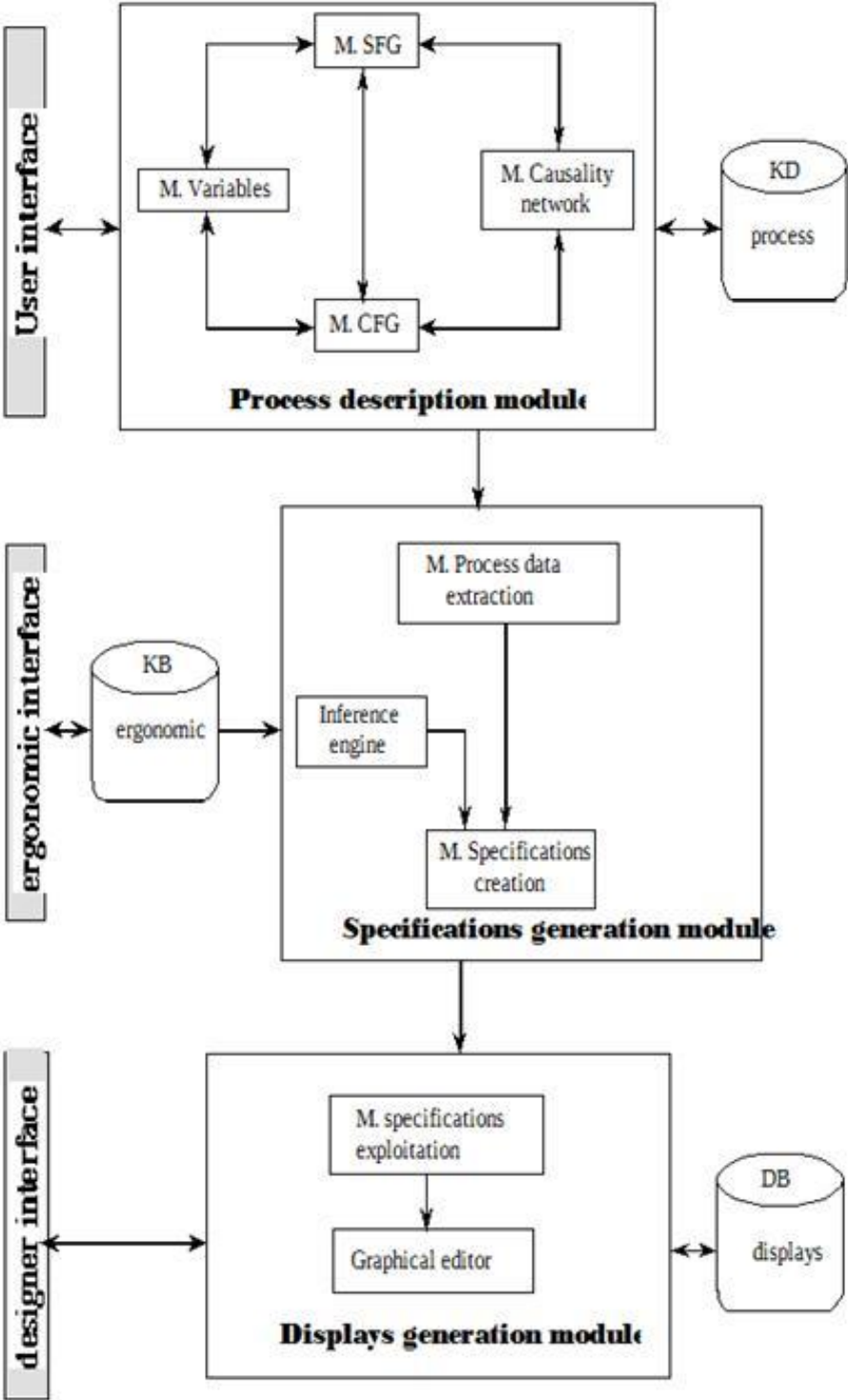


Fig. 2. Architecture of ERGO-CONCEPTOR

AN APPROACH TOWARDS "INTELLIGENT" ERGONOMIC DESIGN

This field can be illustrated by the description of a tool called ERGO-CONCEPTOR. It aims at automatizing several stages of design of man-machine interface for process control (Moussa, Kolski, Millot, 1990). The ERGO-CONCEPTOR system relies on the idea that it is possible to automatically generate graphical views from an exhaustive description of the process. This description is made according to various abstraction levels while taking account of control objectives (in terms of tasks to be achieved by the operators).

ERGO-CONCEPTOR includes three main modules (see Fig. 2) : (i) the first one is used for describing a process. This description must be guided by the operator's informational needs, (ii) the second module allows the automatic generation of the file of specifications by exploiting the ergonomic knowledge stored in a knowledge base, (iii) finally, the third module gets back the file of specifications which was generated by the previous module and thus creates graphical displays.

Process Description according to the Human Operator Needs

With a goal of implementation in ERGO-CONCEPTOR, a method to describe the automated process has been proposed by Moussa, Ben Hassine, Kolski (1991) and Moussa, Kolski (to appear). The basic concepts on which the methodology is built on, are presented below.

The Simple Functional Group (SFG). It's a sub-system - which can not be broken down - and which is presented as a set of variables reflecting its state at any moment. It allows to control an irresolvable function. The SFG resources are the variables forming it and called intrinsic variables. The links between the different sub-systems are described by input-output links. The information transported by the inputs and outputs of a SFG are represented by variables called communication variables.

The Composed Functional Group (CFG). It's a grouping of sub-systems forming a sub-system of a higher level of abstraction. The elements of a CFG - which can be SFG or CFG - represent the resources of the current CFG which have the purpose to control a macro-function.

The causality network. Further to the structural description the process, the third main concept is the functional description. It is done from the representation of the interactions between different variables of a sub-system by influence links grouped in a causality network. The role of the link is to describe the impact of a variable perturbation of a FG on the rest of the system.

So, the process functional and structural descriptions are completed. It is then necessary to describe the system in terms of the hierarchy of abstraction "means-goals". At the abstraction level N_i , the goals of a given system S_i can be reached by acting on the sub-systems of N_{i-1} level forming it. At the abstraction level N_{i+1} , this sub-system S_i is considered as being a means or a resource allowing to realize the sub-system S_{i+1} which include it. This description allow to have an idea which is precise enough to deduce the specifications of the interface to be designed.

Automatic Generation of Interface Specifications

The second module includes three given sub-modules : (i) the sub-module of data extraction, (ii) the inference engine and (iii) the sub-module of specifications creation (see Fig. 2). The first sub-module is in charge of the extraction of the data describing the process from the data base "process". The second sub-module is focused on the ergonomic side of the system. To that end, several ergonomic rules have been stored in a knowledge base. A specific inference engine, working in a forward chaining, passes on the results to the next sub-module. The ergonomic rules have to make apparent : (i) for each functional group, the different types of displays which have to be foreseen, (ii) for each type of display, the different zones forming it and the different modes of representation of the sub-system state, (iii) for each mode, the ergonomic aspects relative to the representation of information which have to be implemented (for example : ergonomic rules about colours, characters size, and so on).

The ergonomic knowledge formalization consists on the one hand in stating some concepts and rules for the information graphical presentation and the display structuration and on the other hand in formalizing them in production rules. These production rules are exploited by an inference engine working in a forward chaining. The mechanism of the knowledge processing is based on the classic sequence : definition of all the applicable rules, execution of the rule and updating. The formalism of the production rules is : *If Condition Then Conclusion*. The knowledge base contains about 50 rules.

A sub-module of specification creation allows to generate a specification file while respecting a predefined syntax. The content of the specification file describes for each view : its type (supervision, control...), the concerned sub-system, the zones it includes (structural definition) and the contents of each zone (informational entities).

Graphical Displays Generation

From the specifications file of the graphical displays, which results from the previous module, this module is charged to assist the designer during the effective generation of graphical displays. This semi-automatic generation of the graphical displays follows this step : (i) the system analyses the specifications file in order to deduce the set of information which is necessary to realize the graphical displays. This analysis is based on the lexicon defined in the previous module. (ii) The operator use the "intelligent" functionalities of the graphical editor which integrate the process knowledge. These functionalities exploit all the information describing the structure and the functionalities of the displays, and elementary graphical routines to generate the process graphical displays. (iii) The operator can use "classic" functionalities of a graphical editor according to two complementary aspects : on the one hand, graphical routines, like designing a rectangle, a circle, editing a text, and so on, are used as inputs -under the form of graphical objects- for the "intelligent" editor, on the other hand, this editor ensures a high degree of freedom for the displays designer. The latter can refuse some of the suggestions made by the "intelligent" editor. He can modify at any time a part of the display which is automatically generated by the intelligent functionalities, and even do completely without it so as create his personal displays. In order to do it, in addition to the basic graphical routines, the interface suggests to the designer -under the form of a text, the necessary specifications concerning the process to help him to design the displays.

First Results

First tests have been made in laboratory. From the schemas of a nuclear power plant, we have realized a human-machine interface permitting to control it. Of course, we have started from the hypothesis that the human task analysis has been made, and that the operator tasks amount to the supervision of the different sub-systems constituting the nuclear power plant. In case of dysfunctioning, the operator has to make a diagnosis, to evaluate the tendency of variables and to correct by using directly the interface.

According to the methodology described, the nuclear power plant has been split up into an arborescence : 16 SFG and CFG, and 50 interconnected variables have been described. For the data description in the first module, about four hours were necessary. The automatic generation of the specifications has taken about 2 minutes. Then 55 graphical displays have been created. Using systematically the specification proposed by the expert system, the designer needs around 30 seconds for each display created. An example of view can be seen in (Kolski et Moussa, 1991). Another article is planned to describe entirely this first application of ERGO-CONCEPTOR.

The results obtained by this first model are encouraging insofar as it was quite easy to realize some first control displays according to this methodology. It remains to be realized the animation module of the generated displays. This module has to take into account other ergonomic rules for the dynamic presentation of the display graphical objects. Furthermore, ERGO-CONCEPTOR proposes to the designer several ergonomical representation modes adapted to the control tasks. But, of course, the control displays, issued from ERGO-CONCEPTOR, must be validated with the operators. Nevertheless, the first laboratory version of ERGO-CONCEPTOR permits to consider in a promising manner the "intelligent" ergonomic design of man-machine interface for the industrial process control. This system is being validated on several simulated industrial process (Moussa, Kolski, Millot, 1992).

AN APPROACH TOWARDS "INTELLIGENT" ERGONOMIC MANAGEMENT

Our research works in the field of "intelligent" ergonomic management of man-machine interface concern particularly man-machine cooperation problems. These works aim at optimizing in real time the information communication between the human operator and a decision support system, using the "intelligent interface" notion (Kolski, Tendjaoui and Millot, 1990 ; Hancock and Chignell, 1989).

The Concept of the "Intelligent" Interface

We call "intelligent interface" an independent interface able to adapt itself to the operator's informational needs, using expert knowledge related to the operational context of the problem to be solved, to the characteristics of the different users of the system and on to the tasks they have to perform. In brief, our approach consists of using an expert system to ensure the communication between the decision support system and the human operator (Tendjaoui, Kolski and Millot, 1990). This "intelligent" approach is tailored to the area of supervisory process control. Its goal is to design an intelligent imagery manager called "Decisional Module of Imagery" (D.M.I.). This approach can be integrated into the global model of the Man-Machine system in automated process control rooms to obtain an overall assistance tool (see Fig. 3) : the supervisory calculator centralizes the whole process scored data. These data

are accessible by both the decision support expert system and the D.M.I. Using this data, the decision support expert system infers information such as predictive, diagnosis or recovery procedures. This set of information is transmitted to the D.M.I., which selects those that can be presented to the operator. This selection is based on a task model to be performed by the operator, and on "operator" model containing information about the operator (Tendjaoui, Kolski, Millot, 1991b).

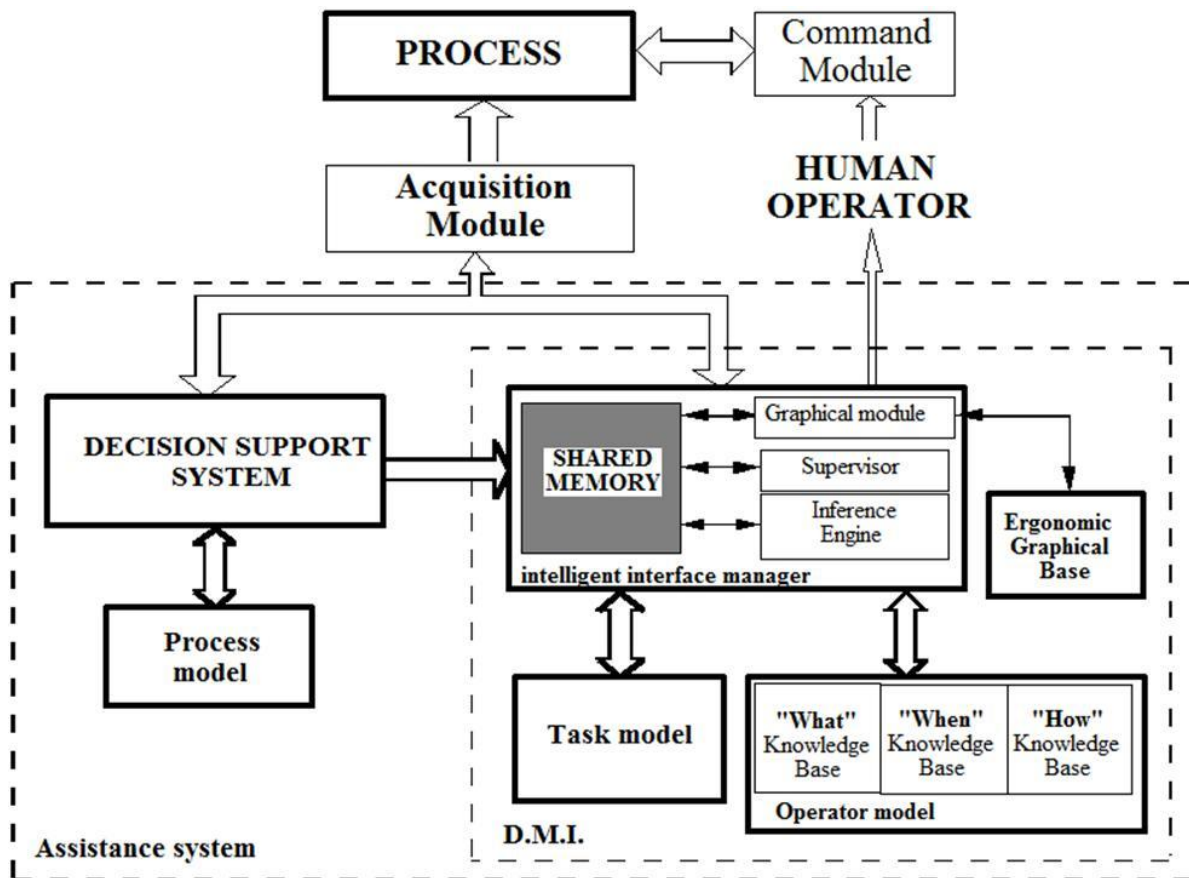


Fig. 3. Global Man-Machine system integrating the Decisional Module of Imagery

The Principles of the Task and Operator Models

The task model is currently restricted to problem solving tasks and results from a previous analysis of fixed tasks which have to be performed by the operator. This model is based on the qualitative general model of Rasmussen (1980). Whereby a task is built through four information processing steps : event detection, situation assessment, decision making and action. This task model contains a set of process significant variables used by the operator while performing his different tasks.

The operator model integrates a set of ergonomic data which is presently limited to : (i) three possible levels of expertise for the human operator (unskilled, experienced, expert), (ii) the type of displays associated to each of the operator's cognitive behavior, corresponding to Rasmussen's model, (iii) the representation mode associated to each type of display

The Aims of the D.M.I.

The aims of the D.M.I are : (i) to select the data that can be displayed on the screen taking into account both the operational context of the process and the informational needs of the operator, in order to enable the operator to supervise the process and to define possible corrective actions when a failure appears; (ii) to define the ergonomic parameters associated with presentation of this information in order to make the human operator's understanding easier; (iii) to add to this supervisory imagery the corrective advice given by the decision support expert system in order to justify its reasoning and thus to prevent possible conflicts between the system and the human operator (Taborin and Millot, 1989).

The "What", "When" and "How " Problems

In order to meet these goals, the D.M.I. has to be autonomous and able to adapt itself to the operators' needs. The D.M.I. must therefore integrate expert knowledge on : (i) the different operational contexts of the system to be supervised; (ii) the characteristics of the different users of the system; and (iii) the cognitive and sensorimotor tasks that these operators have to perform. These types of knowledge allow us to answer the three following questions related to ergonomics considerations : (i) **What** information is to be presented to the operator (we consider here, that the "what" includes the "why", by using justification scales of the information displayed); (ii) **When** shall we display it, (iii) **How** to display it. These ergonomics considerations are more detailed by Tendjaoui, Kolski and Millot (1991b).

The D.M.I. is implemented in an experimental platform that integrates a supervisory system of a simulated process. It is written in "C" language. The platform is based on a VS/3100 station. Graphical displays are created with a graphical tool called DATAVIEWS (V.I. Corporation, 1988). The software architecture of the platform is described by Tendjaoui, Kolski and Millot (1991a, 1991b).

Discussion

In order to optimize man-machine communication, we use Artificial Intelligence techniques and it seems that Artificial Intelligence can contribute solutions to some of the problems encountered in the field of process control/man-machine interaction (Elzer and Johanssen, 1988 ; Millot, 1990).

The first version of the D.M.I., contains approximately 80 rules in the "WHAT" database, 70 rules in the "WHEN" database, and 110 rules in the "HOW" database. These rules are compiled in such a way as to be easily exploited by the inference module that controls the graphics display (for more details see Tendjaoui, Kolski and Millot, 1991a).

At present the D.M.I. attempts to fulfil the following objectives (Tendjaoui, Kolski and Millot, 1991b) : (i) It must adapt itself to the operator. This problem is solved in three steps. Firstly, the D.M.I. uses rules from the "WHAT" database in order to decide which information is to be presented to the operator. Secondly, armed with data on the severity of the problem and the skill level of the operator, the D.M.I. uses rules from the "WHEN" database to decide at which moment this information is to be presented. This temporal control over the display allows the D.M.I. to adapt itself to the different operational situations of the process. Finally, using data known about ergonomic and operator preferences, the D.M.I. uses rules from the "HOW" database to decide on the form of data presentation. (ii) it must help the reasoning of

the operator : the D.M.I. identifies the operators task using information on the severity of the problem and the status of the process, and guides him with useful information.

The D.M.I.'s capacity to adapt and reason has an impact on : (i) The operators learning curve : the flow of information and its level of detail are managed by the D.M.I. according to the experience level of the operators. The D.M.I. can be used as a formative tool and, in a working situation, its characteristics can improve the operators experience. (ii) The operators workload : The operators workload will decrease because the D.M.I. displays only information to the operator that is useful and in a form that he can readily understand.

These points will be analyzed and evaluated at a later date and will almost certainly highlight some shortcomings of the D.M.I., but it is possible to list now some problems that are the object of our current research and that have allowed us to arrive at an evolved system : (i) consideration of the experience that the operator has of all the different sub-processes : he may, for example, be considered an expert in one sub-process and a novice at another. This experience level depends particularly on operator performance, operator error and on unknown situations that the operator may have already solved. (ii) optimizing the adaptation between the state of the process and the mental image of it that the operator has, using the D.M.I. (iii) integrating a human operator model into the D.M.I. in order to identify, in real time, his cognitive task and to provide appropriate support to his decision. (iv) dynamic evaluation of the operators mental workload. (v) Keeping records of uncommon situations and making them available to the operator via the D.M.I. when necessary. The results of the evaluation will be published in others papers.

CONCLUSION

Throughout this paper, we have been able to present our current research works concerning the use of formalized ergonomic knowledge in three different fields : evaluation, design and management of man-machine interface used in the process control. For each field, three representative tools have been described and discussed : SYNOP, ERGO-CONCEPTOR and D.M.I.

These different rule-based approaches are not yet completely validated and it is still necessary to proceed to many rigorous experiments in different cases of evaluation, design and management of man-machine interface. But they offer new and interesting perspectives for man-machine interface designers in process control. Such concepts and principles can be considered in "intelligent" software engineering tools dedicated to process control.

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