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Contributed Paper

Implementation of AI Techniques for "Intelligent" Interface Development

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This paper presents the implementation of AI techniques for the development of an original approach to "intelligent" interfacing. This intelligent interface is called: the Decisional Module of Imagery (D.M.I.). The "heart" of the D.M.I. is an expert system that manipulates three main objects (the WHAT, WHEN and HOW objects) described in the paper. Knowledge specification and representation for the expert system are then explained. Finally, a first technical validation is presented and discussed.

Keywords: Process control, man–machine systems, expert systems, knowledge engineering, inference processes, "intelligent" interface.

1. INTRODUCTION

Due to growing computerization and automation of industrial processes, the human operator is less and less involved in manual control tasks. On the other hand, he has to perform complex problem-solving tasks in control rooms. These tasks often require a high level of knowledge. This complexity may lead to human errors, which can become catastrophic for the installations, for human beings and for the environment (see for instance Three Mile Island or Tchernobyl).[1–4]

In control rooms, the human operator performs his tasks by the use of graphical means, providing him with a restricted image of the installation reality. The man–machine interface consequently plays a vital role in the system's reliability and efficiency. Furthermore, the present tendency consists of assisting the human operator by decision aid tools. These tools use generally artificial intelligence techniques.[5–7]

The dialogue between the assistance systems and the human operator has to be taken seriously into account during the man–machine system design. A solution consists in the development of "advanced" man–machine interfaces. Several advanced interface principles exist that are able to help the human operator during his dialogue with assistance systems and/or the process. The "advanced interface" notion can be found in the literature under a number of propositions to characterize (i) the interfaces using the "intelligence" notion, or (ii) "intelligent" decision aid tools integrating a user interface management system.[7–10] Note that an advanced interface deals exclusively with the problem of dialogue between all the potential partners (humans and machines) of the man–machine system.

With the aim of improving the cooperation between the human operators and the decision aid tools in the control rooms of industrial processes, the research described here concerns the study of an intelligent interface and is aimed at realizing such an interface supervised by an intelligent manager called the D.M.I. (Decisional Module of Imagery).[11–12] The approach consists of using an expert system to ensure this cooperation. It has currently been validated in the laboratory and is integrated into an experimental platform.[7,13]

This paper presents the implementation of AI techniques for the development of this original approach to

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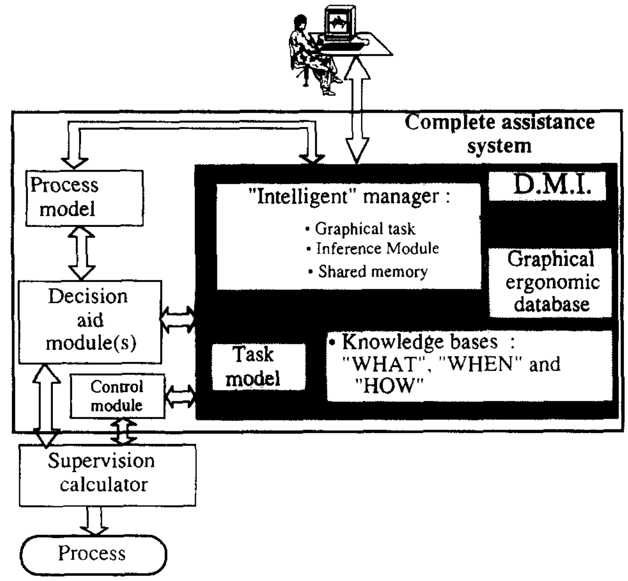

Fig. 1. Global man–machine system integrating the decisional module of imagery.[7]

"intelligent" interfacing. It first describes the D.M.I. and the objects manipulated. Then it explains how the "heart" of the D.M.I. is implemented using artificial intelligence techniques. Finally, a first technical validation is presented and discussed.

2. THE DECISIONAL MODULE OF IMAGERY

The approach is tailored for 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 (Fig. 1). The supervisory calculator centralizes all of the process scored data. These data are accessible by both the decision support expert system and the D.M.I. Using these 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 an operator's "model" containing information about the operator.

The task model is currently restricted to problem-solving tasks and results from a previous analysis of fixed tasks that have to be performed by the operator. This model is based on the qualitative general model of Rasmussen,[14] 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 currently limited to: (i) three possible levels of expertise for the human operator (unskilled, experienced, expert), (ii) the type of displays associated with each type of operators' cognitive behavior, corresponding to Rasmussen's model, (iii) the representation mode associated with each type of display.

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 the presentation of this information for the human operator to understand more easily; (iii) to add to this supervisory imagery the corrective advice given by the decision support expert system to justify its reasoning and thus to prevent possible conflicts between the system and the human operator.

3. THE OBJECTS MANIPULATED BY THE INTELLIGENT INTERFACE

The aim of the D.M.I. is to behave in a self-governing way, and to be able to adapt itself to the operators' needs. Thus, it must include knowledge about: (i) the various operating contexts of the supervised system, (ii) the operators who are going to use the interface to supervise the system, (iii) the cognitive and sensorimotor tasks of the operators. This knowledge will allow the giving of answers to the three ergonomic problems that follow (Fig. 2):

(i) WHAT must be displayed to the operator? This question means: what is the relevant and useful knowledge to display, taking into account the human perception limits and the bounded size of the screen? The authors believe that the "What" question includes the "Why" question by explanation levels in the displayed information.

(ii) WHEN will the selected information be displayed? The right time for a particular display will vary,

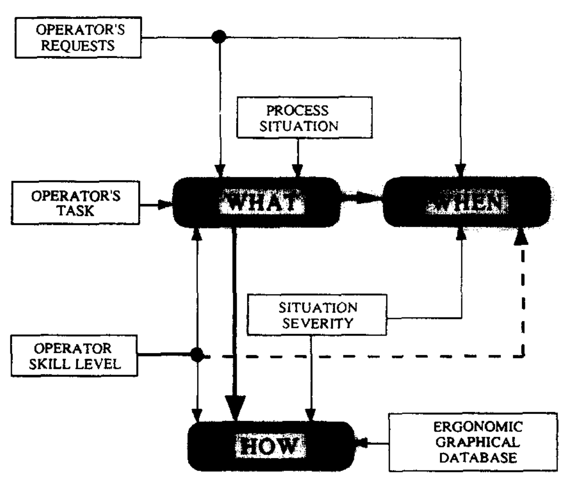

Fig. 2. The "What–When–How" concept.[7,12,13]

especially in taking into account the process operating context.

(iii) HOW will it be presented? This means: what are the most suitable representation modes, seen from an ergonomic point of view?

The "What", "When" and "How" problems are successively described below.

3.1. What

The point of "what to display to the operator" represents the information set that the human operator is due to have at his disposal, on his screen, in order to carry out his supervisory and control tasks. So, the answer to the question of "what" must consider a set of functioning parameters of the human–machine system (see Fig. 2). It depends essentially on three criteria:

—*The operator's requests*

They are connected to the information set that the operator may need at a given stage of the task execution. The operator explicitly asks for these information displays. However, their appearance may differ according to the current context. If the operator asks for one particular type of information, like the current state of a variable or some justifications about the action advice, then the D.M.I. must respond to the request.

—*The operator's class*

This parameter expresses the differences existing between the system users. These differences can be felt at the level of the functions of the human operators (maintenance technician, supervisor, watch keeper, control room operator), at the level of their respective experience in that function, or at the level of any other professional consideration. If the decision support tools perceive an error in the system and propose advice or an action, the operator can (i) be in agreement with this advice and act accordingly, or (ii) disagree and request some justification for the advice. The level of detail in this justification will depend on the operator's skill level, e.g. a novice operator will tend to require more detailed justification than an experienced operator. The D.M.I. must take this into consideration.

—*The operator's task*

The operator's tasks and therefore his informational needs will change according to the state of the process. Indeed, with the aim of responding to the operator's requests during the execution of one of his tasks, the D.M.I. must know what is the current execution stage of the operator's task. The D.M.I. uses this data to select and prepare the most useful information. With this goal, the D.M.I. is based on the knowledge of the process functioning situation. In Fig. 3, the various intervention types of the D.M.I. are displayed, as well as the types of messages and displays that can be required by the operator, according to the possible functioning states of the process. For example, in a

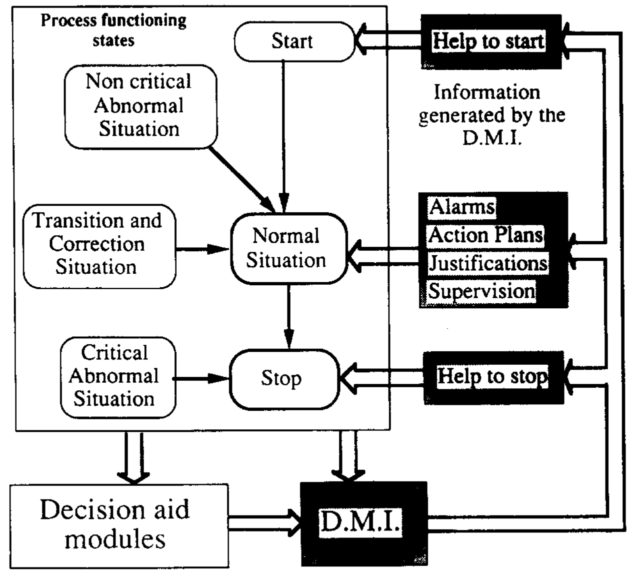

Fig. 3. Examples of assistance to the operator according to the different situations of the system supervision.[7]

transition situation, the operator may need some advice on the way to start the process, whereas, to assess the effects of a corrective action, the operator needs information about the progression of the correction. During an abnormal process state, alarms are automatically selected and displayed, but where an "uncommon" abnormal situation develops, the D.M.I. can focus on the variables that can affect the production and/or the security of the system, by suppressing all of the information and alarms that do not affect either production or safety.

3.2. When

The question of "when information will be displayed to the operator" concerns the choice of the time when the information is most useful. This question is of great interest because it can contribute to the management of the operator's workload, in modulating the data flows coming from the decision aid modules, in accordance with the situation severity of the man–machine system (Fig. 4). According to which information to display and to the operator's requests, the D.M.I. must evaluate the situation severity to determine if the information is going to be displayed instantaneously or later.

The reaction to the problem concerning "when" relevant information has to be presented to the operator depends on the nature of the information that he has requested and on the seriousness of any impending situation. Production targets and security constraints bound the severity evaluation. To know when the D.M.I. has to display information, it is first necessary to know what this information represents (the "What"). For example, alarms are displayed to the operator as soon as they occur, whereas information on action or advice, proposed by the decision support tools, are only displayed to the operator when requested or when a process situation becomes hazardous. The "When" problem depends on the information to display (the "What"), on the operator's requests and on the process situation severity (Fig. 2). The evaluation of the situation severity is linked particularly to the risk of breaks in the security and the production constraints.

Such behavior also allows the operator, in some cases, to maintain his knowledge and, eventually, to enrich it. As an example, following the raising of a default, if the corrective plans proposed by the decision aid module are not already displayed, the operator has to elaborate his own plans, without waiting for those of the decision aid module. In these circumstances, the operator uses his own knowledge and avoids, in particular, the problem of "blind trust", that consists in his waiting for, and automatically applying, the plans proposed by the aid module, without any verification of them. That could lead him to lose some of his knowledge, and he would therefore no longer be able, in some cases, to establish a correction plan if the assistance module fails.

3.3. How

The answer to the question of "how to display the information" has great significance. Indeed, it is important that the information is presented under predefined ergonomic and *a priori* evaluated formats. These can be centralized in an ergonomic graphical base, as shown in Fig. 1. If more than one representation mode is available with the same efficiency and in a similar functioning context, the operator must have the possibility of customizing his interface. He can customize it according to his preferences and habits, before the effective realization of his tasks in the process.

From one representation to another, the information may, moreover, lose its importance and relevance. So, many studies have revealed the effectiveness of the choice of the representation modes.[14–17] As an example, some short definitions of "How" follow:

—To visualize the evolution of a variable, a representation using curves is suitable. Indeed, such a representation allows the operator to know about the variable's trends. Additionally, it produces a historical account of the variable;

—if the situation is severe, the red color can be used to attract the operator's attention to this severity;

—the main information is displayed in the top right area of the screen;

—if the functioning situation is deteriorating and if the operator cannot reach any agreement with the aid module about a corrective plan without requiring justifications, these are automatically displayed in a secondary window.

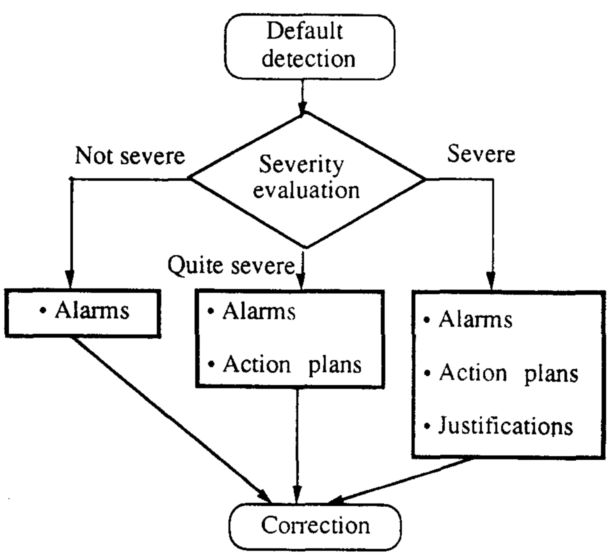

Fig. 4. Example of the automatic management of the aid messages according to the situation severity for a novice operator.[7]

4. THE EXPERT SYSTEM

The "heart" of the D.M.I. is an expert system that is in charge of giving to the supervisor a means of controlling screen displays. Its function is, more precisely, to give answers to the three questions What, How and When (described earlier). It contains (Fig. 5):

—an inference engine;

—a knowledge base on the "What";

—a knowledge base on the "When";

—a knowledge base on the "How".

The *inference engine* handles nine types of fact. These facts represent:

(i) What must be displayed, when and how: "What" (what must be displayed), "When" (when the screen modifications will occur) and "How" (how has the information to be displayed);

(ii) The process functioning state, by the use of the facts: "Functioning_situation", "Situation_severity", "Operator's-task";

(iii) The type of the operator and his eventual requests: "Operator's_class", "Operator's_request";

(iv) The previous state of the interface: "Previous_What" (was displayed at the last step).

These facts may have several values simultaneously because they are used in the management of the screen displays on which more than one change can occur at the same time. For example, in an abnormal situation of the process, with a novice operator supervising the process, the system may have to display, at the same time, a view showing the evolution of the variables and a view with action advice. In that case, two answers are given to the question (What): "What must be presented to the operator?"

Figure 5 explains which are the input and output data used by the inference engine.[7,18] It runs in a data-driven mode because of the need to obtain the highest possible number of facts: all inferable facts are inferred. Facts (ii) to (iv) are part of the initial fact base. A supervisor

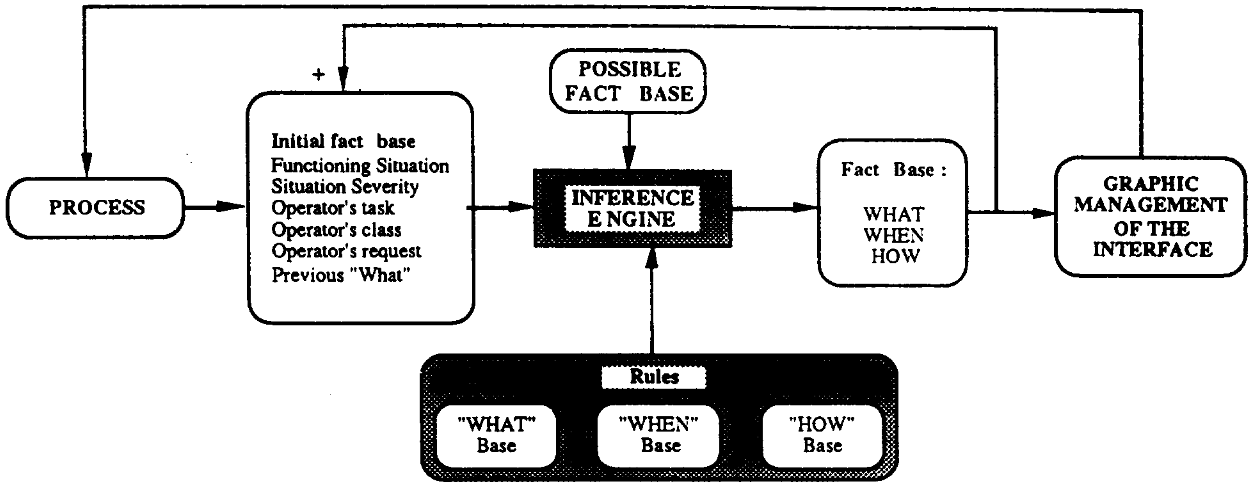

Fig. 5. The D.M.I. inference engine.[7,18]

gives to the expert system the data that is necessary for the constitution of this base. The inference engine uses this knowledge base to deduce new facts: the facts What, When and How that correspond to what must be displayed, when and how it must be displayed. The engine starts by inferring on the fact What. The inferred value(s) of the fact What are added to the fact base and then, the facts When and How are deduced. The rule base is split up into three sub-bases corresponding to those three resulting facts.

"One of the attractions of the expert-system approach lies in the possibility of 'teaching' progressively the initial system in revising or completing the knowledge base put at its disposal".[19] For all that, it is essential for the rule base to be easily modifiable, aiming at a progressive refining. Some rules are added, deleted or modified to improve the rule data base, step by step. With that goal, the rules manipulated by the inference engine are created, compiled and brought up to date, using a methodology developed in the laboratory,[7,20] see Fig. 6.

Four steps compose this methodology:

- The first step leads to a census of all the possible values that are linked to decision criteria about the display management, i.e., the process severity levels, the functioning situations, the needs for assistance tools for the operator's tasks, and so on. This data defines a set of descriptors characterizing the man–machine system. A descriptor is a pair of elements, composed of an attribute and a value. For example, several values can be associated with the "process functioning situation" attribute, such as the values: normal, abnormal and critical. This step leads to the creation of a "Possible Fact Base". It is used to check the validity of the associations between a fact and a value. It contains all the possible values for each fact.
- With the Possible Fact Base, a connection was built between the registered decision criteria and the potential decisions of the D.M.I. These decisions concern "What", "When" and "How". A base of examples is generated during this second step. The description of the examples is made with the help of nine attributes related to the studied problem. Each attribute owns a finite number of mutually exclusive values.
- On the example base, techniques derived from the machine learning domain were used to generate

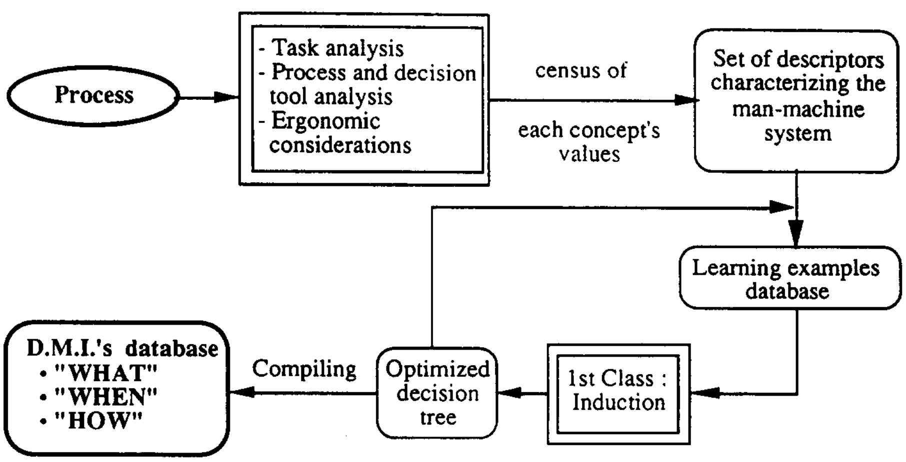

Fig. 6. Method for constructing the knowledge data base.[7,20]

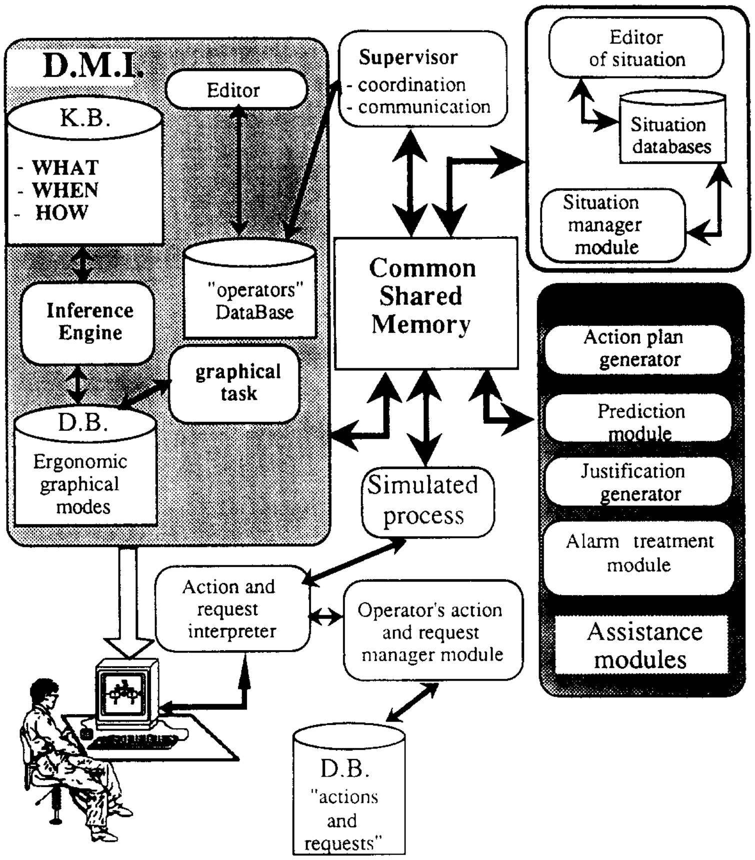

Fig. 7. Experimental platform architecture.[7,13]

optimized decision trees. The Artificial Intelligence tool FirstClass creates the trees. This tool is based on the algorithm ID3 (Iterative Dichotomizer 3), that develops classification procedures expressed under the shape of decision trees, from a set of examples, called the learning set.[21]

• The last step is aimed at compiling these threes into a usable form for the D.M.I. They are therefore changed into production rules, used by the previously described inference engine. The technique used is based on syntactic analysis, which necessitated the definition of an appropriate grammar. The program that "reads" the decision tree and produces the corresponding rules, is a kind of "transducer" or "compiler": with a stack system and with pointers, the tree from FirstClass is translated and the production rules are built in a useful format for the expert system. This operation is repeated three times to build the three modules of the rule base (the modules "What", "When" and "How"). All of the rules belonging to the module "What" have, in the conclusion part, a descriptor as follows:

What = *a value*. Both the other modules are built the same way. In the current state of the D.M.I., the rule base is composed of 335 rules for the three modules.

Three examples of rules are given below:

IF Operator_Class = 3,
AND Severity = 2,
AND Request = No_Request,
AND Situation = Abnormal,
THEN What: = Action_Plan,
AND What: = Deep_and_Justified_Fluence_Graph,

IF Request = Help_To_Stop,
AND What = Help_To_Stop,
THEN When: = Now,

IF Operator_Class = 2,
AND Previous_What = Variables,
AND What = Deep_And_Justified_Fluence_Graph,
THEN How: = Detailed_Fluence_Graph.

To evaluate the D.M.I., a testbed was developed. This experimental phase is described below.

5. GLOBAL PRESENTATION OF THE EXPERIMENTAL PLATFORM

The experimental platform, developed in the laboratory on a VAX/VMS computer, is composed of a set of computerized modules sharing a common memory zone, Fig. 7. These modules are:

- The process simulator;
- Many operator assistance functionalities:
  —a prediction module;
  —an alarm treatment module;
  —an action plan generator;

—a justification generator.

- The Decisional Module of Imagery, that integrates:
  —a set of knowledge bases answering the 3 ergonomic questions: "What", "When" and "How";
  —an inference engine that exploits rules contained in the 3 knowledge bases;
  —a graphical task able to manage and to animate continuously all the views of the interface, using the D.M.I.'s answers concerning the "What", "When" and "How" questions;
  —a database about the operators. At present, this one essentially contains information about experiments such as: the subject name, the starting hypothesis for the experiment (novice, experienced or expert), a list of the failure situations used, and a list of the files modified during the experimentation.
- A supervisor module managing the coordination and the communication through the common shared memory.
- A module able to manage failure situations. In an experimental way, each failure situation can be described with a special editor.
- A module able to manage operators' actions and requests. It interprets and saves them into files.

The experimental platform integrates a laboratory simulated process. This one simulates the functioning of a simplified power plant cooling circuit (Fig. 8). It is principally composed of two circuits: a primary circuit (called the Sodium circuit) and a secondary circuit (called the Water circuit). These two circuits communicate through a vapor generator, considered here as a heat exchanger.

The next part of this paper presents some results produced by the D.M.I..

6. FIRST TECHNICAL VALIDATION OF THE PLATFORM IN THE LABORATORY

In order to validate the experimental platform technically, and to verify that what the assistance system gives to the operator conforms to the specified requests, a "first failure" situation has been established. This one is first described. An on-going experiment is then described and commented upon. This experiment aims at verifying the functioning of the whole platform.

A subject is asked to use the D.M.I. and to control the simulated process (see Fig. 8). Some failures were injected in the process according to a scenario. The scenario used for this experiment is described in Table 1. It consists in creating four failures. Each failure is activated for 3 min. In the configuration case of the simulated process, the effects of each failure are described below.

When all of the modules of the platform are activated, variables of the process are set to their nominal values, so that the functioning situation becomes optimal.

A moment later (3 min in this case study), the first failure is activated.

Data scored in this experiment are: the gravity level of the process functioning situation, the kind of view displayed in the principal viewport, the kind of view displayed in the secondary viewport and the subject's

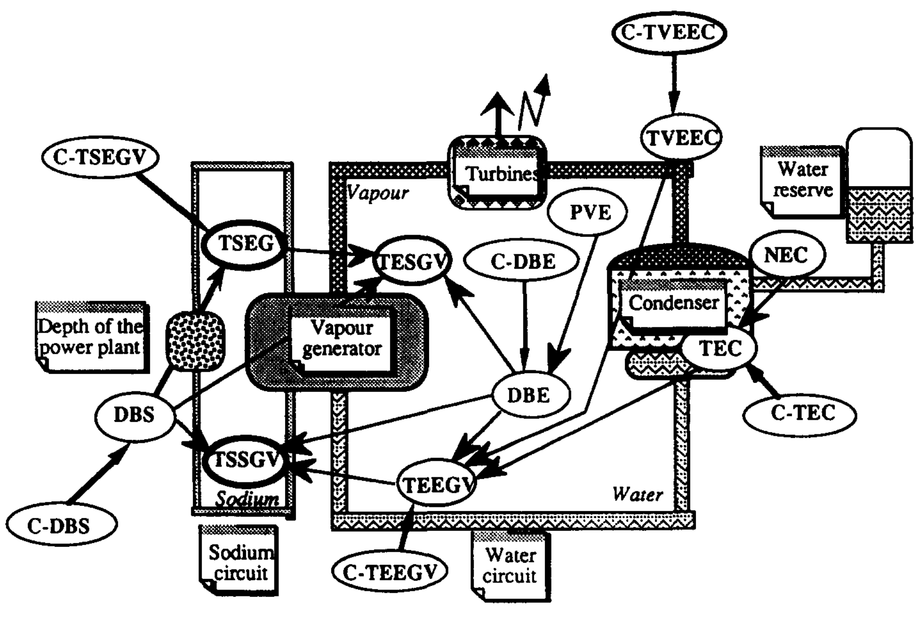

Fig. 8. Localization and influence of variables in the simulated process.[7,13,22]

Table 1. A failure scenario description[7]

Failure activation date	No. and name of the perturbed variable	Amplitude of the created failure (% nominal value)	Generated signs	List of concerned variables
+3 mn	11: C-DBE	+50	TSSGV+ TESGV−	3: TEEGV 7: TSSGV 8: TESGV 9: DBE
+6 mn	10: NEC	+40	TSSGV+	3: TEEGV 5: TEC 7: TSSGV
+9 mn	11: C-DBE	−50	TSSGV− TESGV+	3: TEEGV 7: TSSGV 8: TESGV 9: DBE
+12 mn	10: NEC	−40	TSSGV−	3: TEEGV 5: TEC 7: TSSGV

actions.

The evolution of all the parameters scored is summarised in Fig. 9, which shows:

—the D.M.I.'s decisions, represented by the management of alarms and action plan, as well as by the content of the secondary viewport;
—the answers given to the subject, represented by the content of the principal viewport;
—the subject's activity;
—the evolution of the process functioning gravity (evaluated by the D.M.I.).

The following paragraphs explain progressively the D.M.I.'s decisions without relating all of the inferences.

At the beginning of the scenario (between T0 and T1), and after the detection of the first failure, the

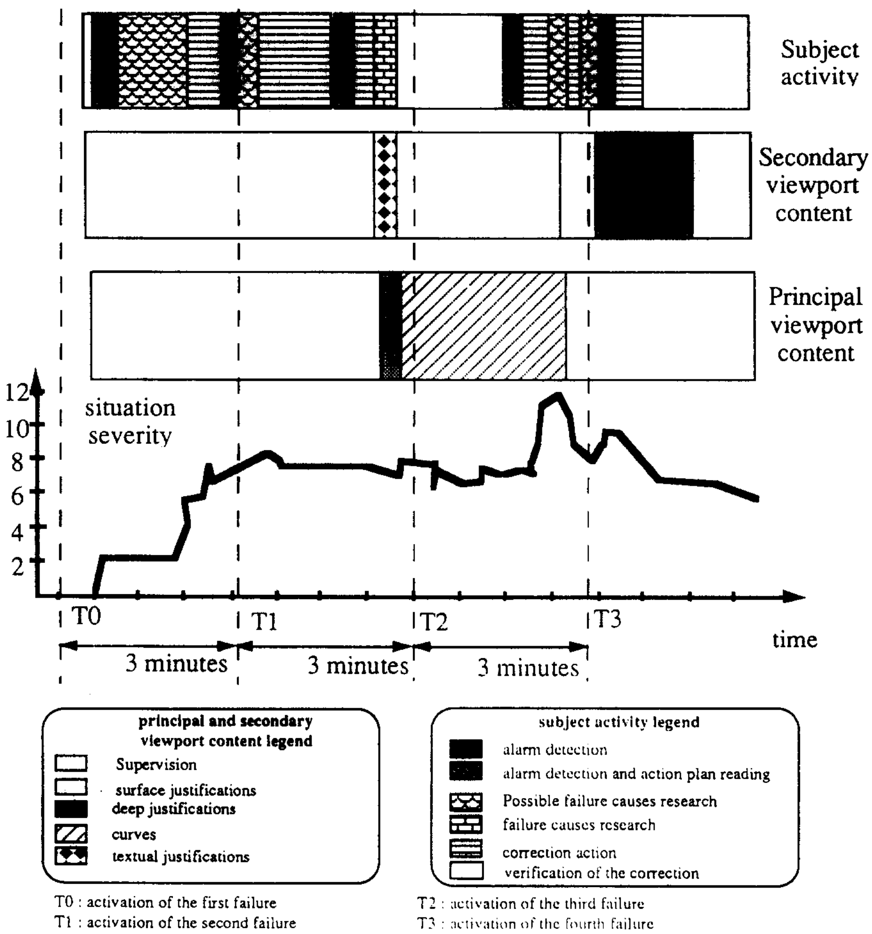

Fig. 9. First experimental results.

Table 2. D.M.I.'s answers between T0 and T1

"What"	"When"	"How"
Action plan	Later	—
Surface justifications	Now	Fluency graph

Table 3. D.M.I.'s answers between T1 and T2

"What"	"When"	"How"
Action plan	Now	Text
Surface justifications	Now	Fluency graph

Table 4. D.M.I.'s answers between T2 and T3

"What"	"When"	"How"
Action plan	Now	Text

Table 5. D.M.I.'s answers after T3

"What"	"When"	"How"
Action plan	Now	Text
Deep justifications	Now	Fluency graph

D.M.I. displays an alarm to the operator. This alarm is immediately detected by the operator. Furthermore, the D.M.I. proposes to the subject a set of possible causes, by automatically displaying surface justifications in the secondary viewport.

In this situation, the D.M.I. answered the questions "What", "When" and "How" in the following manner, see Table 2.

—"What": the D.M.I. deduced that the subject needed an action plan and surface justifications concerning this first failure;

—"When": Since the situation was not serious, the D.M.I. deduced that an action plan should be displayed later, and that surface justifications should be displayed immediately;

—"How": the D.M.I. deduced that surface justifications should be displayed as a fluency graph.

In these conditions, the D.M.I. leads the subject in his search for possible failure causes, because the process situation severity is still low.

In the continuation of the scenario (between T1 and T2), the D.M.I. simultaneously displays both alarm and corresponding action plans. In this case, the process functioning severity is quite high (between 6 and 8) and the subject's aim is to restore the nominal functioning situation of the process quickly. As previously, the D.M.I. proposes to the subject, a set of possible causes, by automatically displaying surface justifications in the secondary viewport.

In this situation, the D.M.I. answered the questions "What", "When" and "How" in the following manner, see Table 3:

—"What": the D.M.I. deduced that the subject needed an action plan and surface justifications concerning this first failure;

—"When": Since the situation was quite serious, the D.M.I. deduced that both action plan and surface justifications should be displayed immediately;

—"How": the D.M.I. deduced that an action plan should be displayed in a textual form, like alarms, and surface justifications in a fluency graph form.

Note in Fig. 9 that when the second failure is activated, the subject changed his behaviour because the process functioning severity was quite high (about 8). He identified this situation by reading the action plan indicating that the failure had to be compensated with only a short delay.

Between T2 and T3, the process functioning severity increased suddenly. In this case, the D.M.I. answered the questions "What", "When" and "How" as shown in Table 4.

At the end of the scenario (after T3), the D.M.I. predicted that a severe situation was coming. In this case, it proposed to the subject an alarm, with the corresponding action plan, and it displayed all the justification details in the secondary viewport. The D.M.I. answered the questions "What", "When" and "How" as portrayed in Table 5.

After having analyzed all the scored data, it is possible to conclude that the functioning of the "Intelligent" Imagery manager is satisfactory, because it has correctly answered the three questions "What", "When" and "How" by displaying information in the secondary viewport automatically and in a coherent way. An example of a screen dump is presented in Fig. 10. It shows:

—an alarm and an action plan;

—a set of possible failure causes in the secondary viewport;

—a supervision view in the principal viewport.

Other experiments must be now done so as to complete this first technique validation of the platform.

7. CONCLUSION

This paper describes the authors' work contributing to the "intelligent" interface notion, in the field of complex process control. The focus here is on the way in which the "heart" of the interface is implemented with the help of artificial intelligence techniques. The management of the interface displays is condensed in the three questions What, When and How, to which the expert system has to give the appropriate answers.

The experimental platform is technically operational. It is now possible to undertake the next phase: the D.M.I. ergonomic evaluation. Its main objective is to verify that the complete assistance system answers a set of pre-defined criteria. These criteria will consider (i)

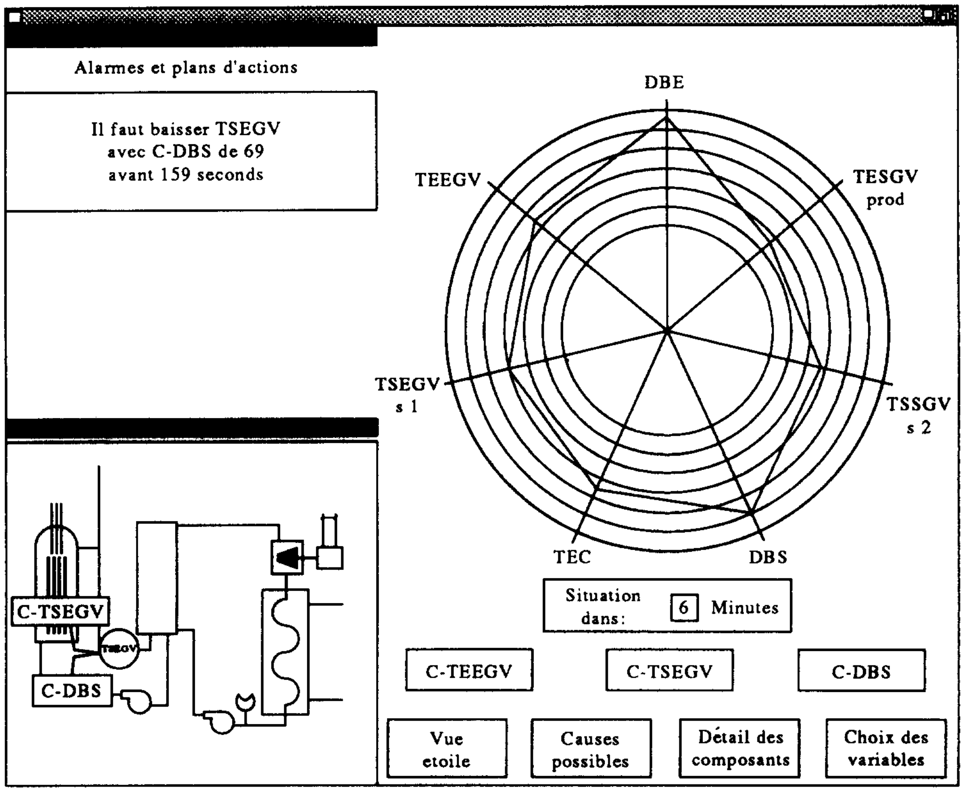

Fig. 10. Example of a screen dump.

system performance, in terms of differences between the objectives and the results obtained, and (ii) human factors related to man–machine interaction, assistance system utilization and human tasks in the different operational contexts (normal and abnormal) of the process. For instance, the evaluation will concern (i) the adequacy of the information to the real needs in the different human tasks, (ii) the access to the control displays and the interface functions, (iii) the chaining between the control displays corresponding with the cognitive steps for performing the tasks, (iv) the access time to information, (v) the human workload, and so on. At present, many operational methods exist for evaluating an assistance system.[23–25] Most of them are commonly used in the authors' laboratory.

The D.M.I. ergonomic evaluation using the experimental platform will probably lead to the evolution of this "intelligent" interface approach.

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REFERENCES

1. Rasmussen J. *Information Processing and Human–Machine Interaction. An Approach to Cognitive Engineering*, North-Holland series in system science and engineering (Sage A. P., Ed.). North-Holland, Amsterdam (1986).
2. Sheridan T. B. Task allocation and supervisory control. In *Handbook of Human–Computer Interaction* (Helander M., Ed.). Elsevier Science, North-Holland, Amsterdam (1988).
3. Millot P. *Supervision des Procédés Automatisés et Ergonomie*. Editions Hermes, Paris (1988).
4. Millot P. Coopération homme-machine: exemple de la téléopération. *J. GR Automatique*, 17–19 October, Strasbourg, France (1990).
5. Boy G. *Assistance à l'Opérateur: une Approche de l'Intelligence Artificielle*. Editions Teknea, Toulouse, Octobre (1988).
6. Taborin V. Cooperation entre opérateur et système d'aide à la décision pour la conduite de procédés continus: application à l'interface opérateur système expert du projet ALLIANCE. Thèse de Doctorat, Université de Valenciennes (1989).
7. Tendjaoui M. Contribution à la conception d'interface "intelligente" pour le contrôle de procédés industriels: application au Module Decisionnel d'Imagerie. Thèse de Doctorat, L.A.I.H., Université de Valenciennes (1992).
8. Zachary W. A cognitively based functional taxonomy of decision support techniques. *Human–Comput. Interaction* **2**, 25–63 (1986).
9. Hancock P. A. and Chignell M. M. *Intelligent Interfaces: Theory, Research and Design*. North-Holland, Amsterdam (1989).
10. Hefley W. E. Architecture for adaptable human–machine interface. In *Ergonomics of Hybrid Automated Systems II* (Karwowski W. and Rahimi M., Eds), pp. 575–585. Elsevier Science, North Holland, Amsterdam (1990).
11. Tendjaoui M., Kolski C. and Millot P. Interaction between real-time aid expert system, intelligent interface and human operator. *Int. Symp. Computational Intelligence 90 "Heterogeneous Knowledge Representation Systems"*, Milano (1990).
12. Kolski C., Tendjaoui M. and Millot P. An "intelligent" interface approach. In *Ergonomics of Hybrid Automated Systems II* (Karwowski W. and Rahimi M., Eds), pp. 587–594. Elsevier Science, North Holland, Amsterdam (1990).
13. Tendjaoui M., Kolski C. and Millot P. An "intelligent" approach for ergonomic design of man–machine interfaces in process control. *Int. J. Indust. Ergon*, **8**, 345–361 (1991).
14. Rasmussen J. The human as a system component. In *Human Interaction with Computer* (Smith H. T. and Green T. R. G., Eds). Academic Press, London (1980).
15. De Keyser V. Etude sur la contribution que pourrait apporter l'ergonomie à la conception des systèmes de commande et d'alerte dans des industries de transformation. Luxembourg, rapport S/79/45, volumes 1 et 2 (1980).
16. Kolski C. Contribution à l'ergonomie de conception des interfaces graphiques Homme–Machine dans les procédés industriels:

application au système expert SYNOP. Thèse de Doctorat, Université de Valenciennes (1989).

17. Taborin V. Cooperation entre opérateur et système d'aide à la décision pour la conduite de procédés continus: application à l'interface opérateur système expert du projet ALLIANCE. Thèse de Doctorat, Université de Valenciennes (1989).
18. Le Strugeon E., Tendjaoui M. and Kolski C. Knowledge specification and representation for an "intelligent" interface devoted to process monitoring and supervision. *IFAC Symp. Artificial Intelligence in Real-Time Control*, Delft, The Netherlands (1992).
19. Farreny H. and Ghallab M. *Eléments d'Intelligence Artificielle.* Hermes, Paris (1987).
20. Tendjaoui M., Kolski C. and Millot P. Knowledge based interface approach for real-time aid expert system. *IFAC/IMACS "SAFEPROCESS'91" Symposium*, Baden-Baden (1991).
21. Quinlan J. R. Discovering rules by induction from large collections of examples. In *Expert Systems in Microelectronic Age* (Michie D., Ed.) Edinburgh University Press, Edinburgh (1983).
22. Kolski C., Tendjaoui M. and Millot P. A process method for the design of "intelligent" man–machine interfaces: case study: "the Decisional Module of Imagery". *Int. J. Hum. factors Manufact.* **2**, 155–175 (1992).
23. Wilson J. R. and Corlett E. N. (Eds) *Evaluation of Human Works: a Practical Ergonomics Methodology*. Taylor & Francis, (1990).
24. Abed M. Contribution à la modélisation de la tâche par outils de spécification exploitant les mouvements oculaires: Application à la conception et à l'évaluation des interfaces homme–machine. Thèse de Doctorat, Université de Valenciennes (1990).
25. Senach B. Evaluation ergonomique des interfaces homme–machine: une revue de la littérature. Rapport de recherche INRIA, Sophia Antipolis, n° 1180 (1990).

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