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Proceedings Tenth European Annual Conference on Human Decision Making and Manual Control, Liège, Belgium, 11-13 November, 1991.

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Abstract

This paper aims at studying the prototyping notion on one hand, and analysing its contribution to the design and evaluation of industrial process supervision synopsis on the other hand. The state of the art of interface evaluation techniques is presented. The notion of prototyping as a design/evaluation techniques is proposed. We illustrate this study with two applications: ERGO-CONCEPTOR (laboratory application) and ATLAS (industrial application).

1. Introduction

The design and the evaluation of process control synopsis are actually subjected to a lot of researches, leading to methodologies, techniques, tools and models already operational or currently to being validated. In this domain, a lot of synthesis and classifications exist in the literature. For example, DANIELLOU [1] and MILLOT [2] describe global methodologies for Man-Machine System design. HANCOCK & CHIGNELL [3] and KOLSKI & al. [4] propose methodologies for intelligent interface design. TABORIN [5] and MANDIAU & al. [6] make an inventory of the different types of aid tools in industrial process control rooms. SENACH [7][8] and WILSON [9] make an inventory of interface evaluation techniques, and so on.

The aim of our researches is to contribute to the design and evaluation of Man-Machine Interface by using the prototyping notion. This paper is composed of five parts: the first one introduces the context of the domain by presenting the mental and physical activities of the human operator, for whom the control and supervisory tool is realized. The second part focuses on the different models involved in a process of man-machine interface design/evaluation. The third part makes a brief inventory of evaluation techniques issued from the literature. The fourth part of this paper deals with prototyping as a design/evaluation methodology. The last part describes two approaches of prototyping systems, which are currently developped in the LAIH.

2. Mental activities and physical activities

Before studying and discussing this domain, it is necessary to locate the supervisory task. The supervision activity, according to the models proposed by RASMUSSEN [10] and NORMAN [11], is made of six steps: perception, interpretation, evaluation, intention, action specification and execution (see figure 1).

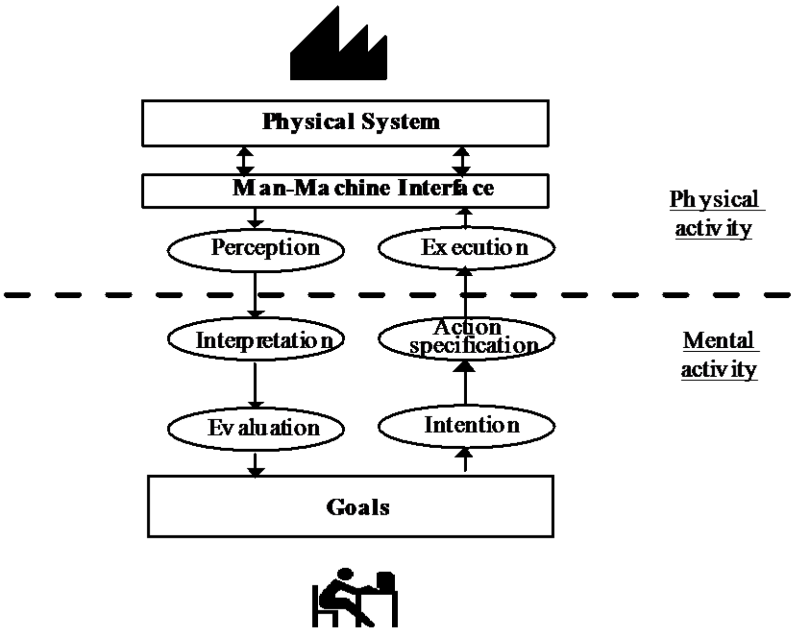

Figure 1: Mental and physical activities of the human operators involved in a control supervisory task.

When a default appears, the operator interpretes and estimates the process state. Then according to the operatory goals, he translates his intentions into a sequence of actions that he performs on the process. NORMAN distinguishes in this interaction two types of variables: the physical variables, corresponding with process variables (temperature, pressure...) and the psychological variables, with which the operator estimates the process states.

During his supervisory task, the operator must first translate the physical variables into psychological variables, with a view to estimate the situation. In a second time, the translation of psychological variables into physical variables allows him to specify the actions to work up. During the process evaluation stage, the operator compares the states of system with the initial goals and intentions. Now the interaction problem is stated in terms of compatibility with the operator model and the system image [12].

This approach shows the importance of the supervisory interface. Indeed, this one must facilitate the correspondence between the psychological and the physical variables on one hand, the stating of associations between physical variables and control mechanisms on the other hand [13]. So the control and supervisory operator builds a mental model issued from the interface utilization. But the models of the other actors concerned by the evaluation/design process may also influence the mental model described above. This point is debated into the following part.

3. The models used during the design and the evaluation of interfaces

Our study is based on a statement admitted by most of the researchers: the users develop their own mental model of the system, through the information supports (interfaces, control handbook...). Consequently, a critical problem concerns the design of these information supports.

Therefore, the design step involves various actors: the operators, the process experts, the designers. Each of them have his own mental representations of the process to interface according to his knowledge, his experience and his application domain. Thus NORMAN distinguishes several aspects during the design step: the first one is physical and the two others are mental :

- THE SYSTEM IMAGE: it is issued from the physical structure of the system which has been built, including documentation, man-machine interfaces...

- THE DESIGNER MODEL: this mental model is based on a conceptualization of the system by the designer. This model, realized from a study of the process to interface, requires expertise and an analysis, which take into account operators tasks as well as their requests and their limits.

- THE USER MODEL: this model does not issue from the designer model, but from the way the operator interprets the system image.

The interpretation of mental model of expert by the designer, and the building of the user model through the interface involve possible errors. By this way, the ergonomist can improve the communication between the different actors by developing appropriate tools [12]. Favoured by the technological evolution in data processing, the works leaded by BODKER and GRONBAEK [14] show the relatively interest of a **cooperative**, **collaborative** and **participative** design, based on common tools.

Furthermore, it is interesting to note that solving a problem (considering the variety of the techniques and the complexity of the means) implies global methods. Those one contribute to proceed efficiently from the problem to the solution definition. Such a method constitutes a methodology according to CALVEZ [15]. In the man-machine interfaces domain, such a methodology will permit on one hand to make designers sensitive to the ergonomic problems, and on the other hand to improve their thought. Therefore, the understanding of the problem and the interfaces definition will be improved. At present, the actors of man-machine interface design/evaluation process can use a set of evaluation methods, briefly reminded below.

4. Techniques for interface evaluation

Numerous interfaces evaluation techniques currently exist. They are stemed from human engineering, psychology and ergonomics. In his very complete study, SENACH [7][8] has classified those techniques according to two approaches (figure 2) :

The **analytic approach** aims at controlling the interface quality, according to a model *a priori* defined:

- This model may take the informal aspect of a human valuation or of an ergonomic evaluation checklist, like the GILMORE, GERTMAN and BLACKMAN's one [16],

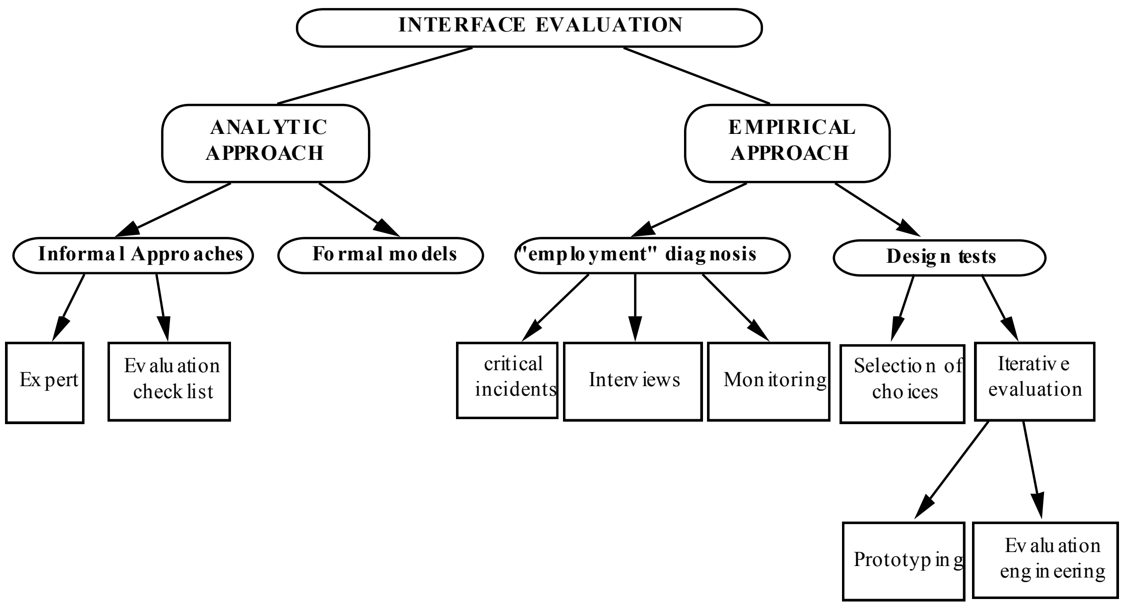

Figure 2: Classification of the methods of man-machine interface evaluation.

- This model may be materialized by means of methodologies and formal tools : we may distinguish the predictive models, like GOMS and Keytroke [17] or the linguistic models like ALG (Action Language Grammar), issued from REISNER's works [18] and CLG (Command Language Grammar) proposed by MORAN [19]. We may also distinguish the CCT model (Cognitive Complexity Theory) of KIERAS and POLSON [20], which aims at formalizing the complexity notion, from the system user's point of view. This list is not exhaustive. Other models can be quoted, like the formal models of the interface quality such as SYNOP [21]. They are interested in measurable properties of the interface and this, in a more technical point of view than the previous models. The SENACH's classification [7] distinguishes two approaches: (i) a cognitive approach of the interface quality which takes into account the processing realized on the information, (ii) an optimal approach of its quality, which does not consider the semantic aspects and evaluates the interface according to quantitative criteria related to the information presentation. These different models are described by SENACH.

The **empirical approach** permits an evaluation of the interface from a selection and an analysis of the behavioral data. Those data are issued from interface utilization by representative operators. SENACH [7][8] distinguishes two approaches of empirical evaluation :

- The "employment diagnosis": this evaluation is realized when an experience of system using exist. Different techniques allow to diagnose functions or modes of representation, which may be failing, useless, difficult to use, etc. Three examples of techniques illustrate the "employment" diagnosis: the method of the critical incidents, the interviews and the monitoring (consisting in using an observer in the computerized system). According to SENACH [7], they correspond to different steps of an ergonomical intervention. The information required by man-machine system analysis are defined into levels of details, which are more and more important,

- The design tests : this type of evaluation may be used when no experience of system using exist. Some tests are then realized along the whole design process. When no evident criteria of choice exists, the design test method can be used and the empirical data gathering must then permit to hierarchize the initial solutions. Most of the time, this methodology is realized before the prototyping. The latter will be discussed in the next paragraph. We also distinguish the process of "evaluation engineering": the first version of the interface is evaluated with regard to performance goals. Next an analysis of impact finally aims at obtaining an interface version corresponding to the performance objectives.

5. Prototyping as a design/evaluation method

The appearance of numerous powerful software tools during last few years led to the development of new design/evaluation techniques of man-machine systems. These techniques based on rapid prototyping of man-machine interfaces allowing thereby an iterative design [22]. These software tools can be classified according to three categories [23].

- THE TOOL BOXES (Xtoolkit, Dvtools, Aida, Machintosh toolbox...): they correspond with a set of routines which allow the description of the dialogue from Input/Output devices (mouse, keyboard...). This kind of product necessitates a long and tedious learning of their programming techniques.

- THE INTERFACE GENERATORS (Dvdraw, Masaï...): those tools permit a graphical and/or textual description of the interface. But they are not always compatible with the temporal constraints required for the control of some continuous process.

- THE SKELETONS OF APPLICATION: they correspond with a set of configurable applications applied to process control. This approach is often compatible with the temporal constraints met in process control.

SCAPIN [12] shows that some decisions of design result from compromises between several criteria. Therefore, the use of this kind of tools permit to evaluate the various design possibilities. SENACH moreover proposes a theoretical model of design/evaluation (figure 3).

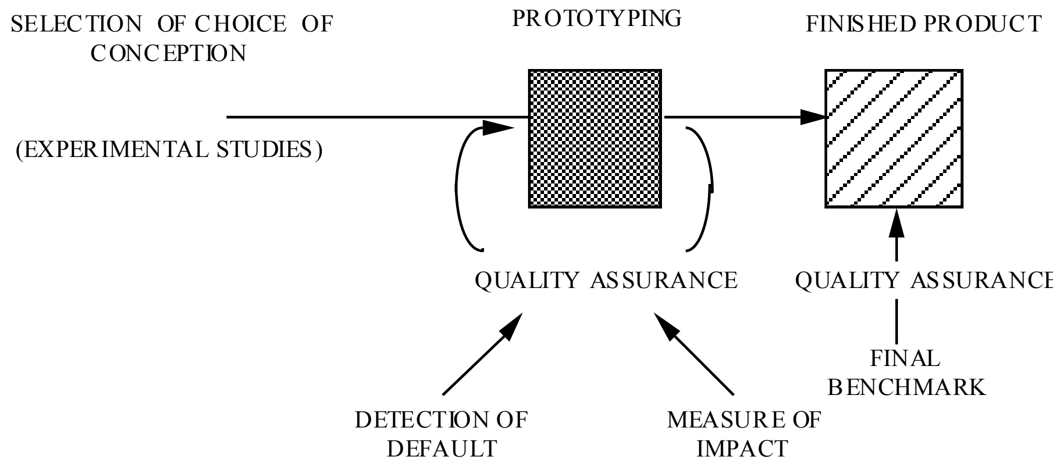

Figure 3: Evaluation steps to consider in the design process

This theoretical model points out the data-gathering techniques used to evaluate the choices of design. Those data allow to analyse the defaults and to measure their impact. BEWLEY'S works [24] (quoted by SENACH [7]) show that it is imperative to precise correctly the objects and also to define appropriate control tasks so as to realize a good evaluation. Most of the evaluations are conducted in a laboratory context, which do not reproduce the real conditions of use (lack of stress and motivation, different working environment...). The final product must then be validated in an real conditions. The ergonomic problems related to man-machine interface design have leaded a lot of researchers to propose methodologies, like MILLOT [2] and TABORIN [5]. We propose a model of supervision synopsis design based on a methodology developed in the LAIH. The design model is inspired by three prototyping notions: exploratory, experimental and evolutive (this model extend the notions presented by GEIB [25]), figure 4.

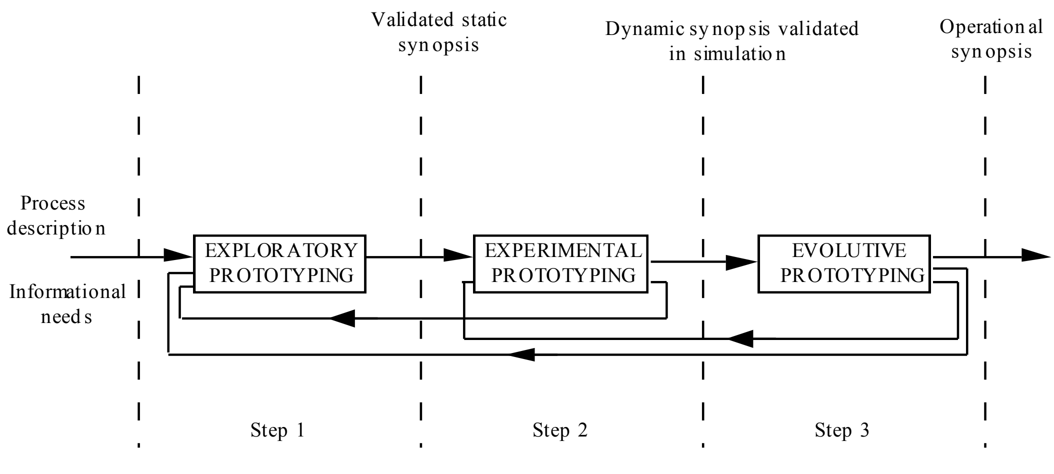

Figure 4: Model of supervision synopsis design

- STEP 1 - **The exploratory prototyping**: This step consists in describing all the static displays of the synopsis, by means of a process description and a definition of operator's informational needs. This approach permits on one hand to validate the specifications of man-machine interface (number of views, their chaining, their parts...) and on the other hand to define the adequate representation modes. The use of a prototyping tool for this step may contribute to a better communication between the different actors (operators, process experts, designers, ergonomists) and so may improve the specification phase.

- STEP 2 - **The experimental prototyping**: It is necessary to describe the dynamic aspect of displays and to evaluate them. This evaluation is made in simulated situations. Therefore it needs to generate representative scenarii of process functioning.

- STEP 3 - **The evolutive prototyping**: As the synopsis is realized (static and dynamic aspects), it is necessary to put it back on a real context. This evaluation permits to verify if the synopsis answers to the needs required by the human supervisory tasks.

The proposed design model is based on a serial of design/evaluation steps. It presents several advantages:

- The establishment of a dialogue between the designers and the users. A lot of experts of man-machine interaction agree that the potential users are disposed to accept a system, if they participate to specification and if some of their suggestions have been taken into account [26].

- The possibility to evaluate the synopsis at the key points of the design, and therefore to facilitate the early detection of design errors.

- The increasing of the designers though during the specification step. Therefore, they apprehend in the better way the problems related to the interfaces design.

This approach may contribute to a decrease of ergonomic problems related to the interfaces design. Nevertheless, some factors must be considered so as to motivate the designer into taking up such a method [22]:

- the easy modification of the prototype contributing therefore to an iterative method of design,

- the ease of use which appears after an acceptable learning period,

- the realistic simulation of the application, in order to respect the system semantics,

- the possibility to recover a piece of software issued from the prototyping step for the finished product (involving a development cost decrease).

Those four points aim at (i) urging the designers to use the prototyping tool and therefore to involve the final user in the design process, (ii) improving productivity and reducing development and maintenance costs. As SOMMERVILLE [27] stated, maintenance costs can be two or three times as much as development costs in the case of complex systems. The experience shows that maintenance costs are mainly due to shifts in the definition of the requirements and not to errors. Then this approach related on rapid prototyping ensures a decrease of project costs insofar as it allows better definition of the requirements. Two examples of prototyping techniques are now described.

6. Two prototyping approaches of Man-Machine Interface design for process control

In order to illustrate this study, this part describes two prototyping approaches about man-machine interface design for industrial process control: ERGO-CONCEPTOR and ATLAS.

6.1. The ERGO-CONCEPTOR system

Considering the specific domain of process control, 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) [28][29]. This system is made up of three modules:

- The first module allows to interactively and hierarchically describe the process while taking account of the operator's prescribed tasks: supervision, default detection, evaluation of situation, decision making and action. This module generates a descriptive database of the application.

- The second module analyses the database content according to ergonomic criteria. A set of interface specifications is generated.

- The third module is a graphical editor. The designer can ask for an automatic generation of the representation modes directly on the screen. A set of graphical functions allows him to modify the displays.

The figure 5 describes the global design process implemented in ERGO-CONCEPTOR. The result is a database of control displays. Three interfaces are used: (i) a "description" interface permits to describe the process characteristics. Different sets of variables are created according to the control operators needs, (ii) an "ergonomist" interface is used to update the ergonomic knowledge bases, (iii) the third interface allows the designer to create the displays.

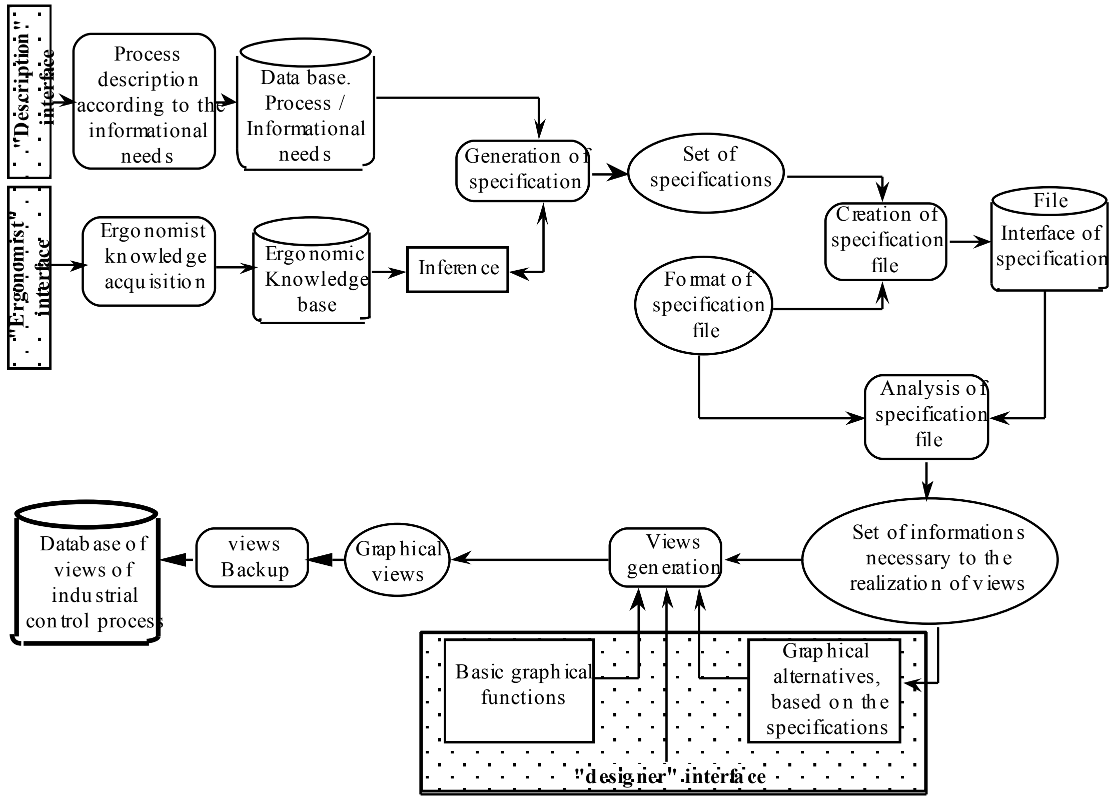

Figure 5: process following by ERGO-CONCEPTOR tool

In addition to its utilization by the different actors of the design process, the interest of this system consists in an automation of several design and realization steps. ERGO-CONCEPTOR proposes to the designer several ergonomical representation modes adapted to the control tasks. The synopsis, issued from ERGO-CONCEPTOR, must be validated by the operators. This system is being validated on several simulated industrial process [30].

6.2 The ATLAS system

The atlas system is issued from a collaboration between CSEE, 3IP* and the LAIH. The aim of this project is to realize a computer aided software engineering workbench, easing the supervision synopsis specifications on one hand and their realization on the other hand.

The temporal constraints, required by the supervision of industrial process, result in the following configuration: a target machine in which data processing tasks used for the supervision are implemented, and a development machine with which the designer specifies his application (figure 6).

The chaining of the different data processing tasks in the target machine is sequential and their function are specific:

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- **Acquisition and filtering**: gathering process data on one hand and validating their measures on the other hand,

- **Logical processing**: defining the different logical states of the process (for instance : a valve is opened, a pump yield...),

- **Animation processing**: making a link between the logical states and the animation states (for example: the valve is opened, therefore his background color is red...),

- **Animation**: modifying the image on the control process screen.

The development machine must permit the designer to specify and to realize his application. Therefore it is composed of different modules described further: a graphical editor, a configurator and a scenarii editor

The graphical editor sustains two functions: the process description and the synopsis description. The process description is based on a systemic analysis method, described by FADIER [31] : the "Diagram-Block" method. It consists in graphically describing the system and its different components, proceeding from the global system downto the elementary components by successive refinements. This method provides a good description of the process and facilitates the dialogue between the different actors. The synopsis description permits to determine the number of views composing the synopsis, their chaining as well as their informational contents (sub-systems to supervise, specific variables...). Process and synopsis databases are created, which are used by the display generation module to realize the static displays of the synopsis.

Thanks to the configurator, and with the displays created before, the designer specifies the dynamic behaviors of his application, by describing the logical and animation equations of the image components. In case of an animation symbolizes a transferring substance (for instance: a hydraulic circuit), a propagation network is automatically built by interpretation of the graphical displays databases.

So as to estimate the synopsis in simulated situations, the scenarii editor allows to generate representative scenarii of the process running. The process is simulated but not modelled because the process modelling requires specific knowledge (for instance qualitative physics), that the designer does not have.

As the set of specifications has been realized, the software interfaces permit the transmission of useful data to the target machine. We can note that during the evaluation in simulated situation, the development machine transmits the process data to the target machine through the simulator.

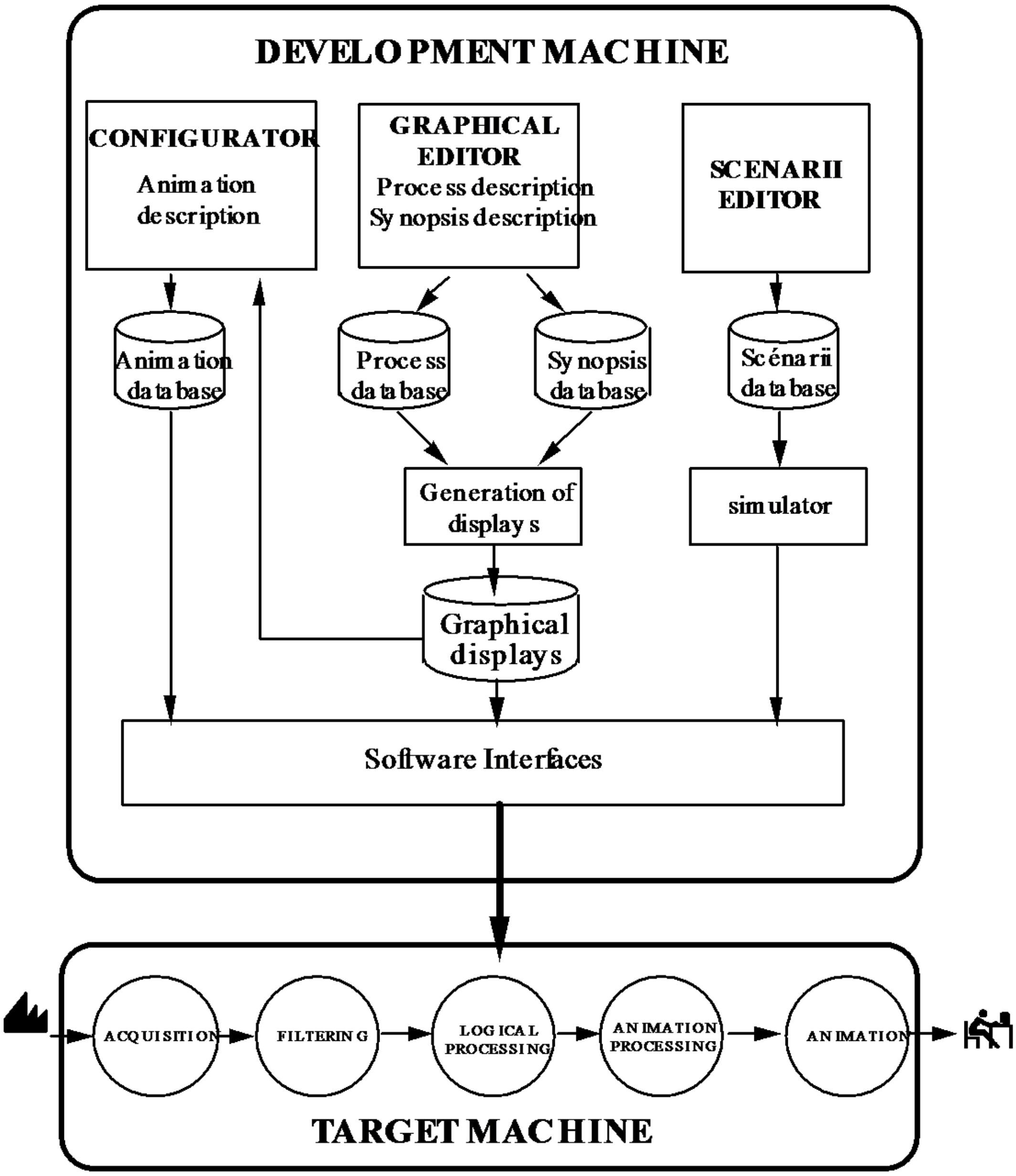

Figure 6: General structure of ATLAS.

The advantage of this system is that it proposes a method of specification/design based on the design model presented in the latter paragraph. Therefore the main constraint of the workbench of synopsis creation that it has to be convivial and easy to use. Thus during the exploratory prototyping phase, the designer graphically specifies his synopsis. After a dialogue between experts, ergonomists and users, the designer may modify the specifications. An experimental prototyping, which aims at verifying the dynamic behavior of images, is then realized with the configurator and editor of scenarii. New estimations are then done. The set of informations issued from these two first steps is then directly used in the third step of evolutive prototyping.

7. Conclusion

Our purpose is to facilitate the design and evaluation of man-machine interfaces, which are to be used in the industrial process control context, by means of prototyping techniques.

After a presentation of the design problem, a conceptual model has been proposed, it is composed of three steps involving prototyping techniques: an exploratory prototyping, an experimental prototyping and an evolutive prototyping. This paradigm has now to be validated.

We are therefore working on two approaches which use such techniques. The first one has been formalized into a system called ERGO-CONCEPTOR which can be used by some actors of the design process. This system is being validated in our laboratory. The second approach aims at building a computer aided software engineering workbench for industrial synopsis design. This system is currently being specified.

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