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Experimental verification of ecological interface prototype issued by an automated generation tool

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Abstract

Vicente and Rasmussen have developed a method called Ecological Interface Design (EID) in the field of cognitive engineering[1]. In this context, we proposed a software tool named Anaxagore,that can assist the EID processfor a rapid implementation of user interface prototypes.In a first stage, models based on standardized structure-functional diagramare computed[2]. In a second stage, these diagrams as inputs are transformed through a model-driven engineering process, involving a library of ecological graphical representations and an interface background. Then, an ecological interface prototypecan be generated. Previously, Anaxagore was used to generate conventional synoptic representation[3]. To validate its EID extended version, an experimental protocol has been established. The experiment was conducted at the National Maritime College, with 14 naval officers randomly divided into two groups according to the used interface. After a preliminary training of participants to the use of the interfaces, four scenarios were simulated during the experiment. For each scenario, the performance was evaluated by a success score and by measuring the time to detect and understand failure.With the EID interface generated by Anaxagore, faster detection time and betterdiagnosis accuracy were observed. Anaxagore seems to constitute a response forassisting the rapid prototyping of ecological interface.

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1. Introduction

In recent years, numerous studies in cognitive engineering have been carried out in the scope of Ecological Interface Design (for recent reviews see [4]; [5]).EID consists in facilitating the perception of the work domain properties that an operator must control during task achievement. Through a preliminary Work Domain Analysis and the respect of a general cognitive principle on compatibility between information display and human information processing capabilities, - named the Skill, Rules, Knowledge framework, user interfaces displaying relevant work domain information for task achievement in complex systems can be designed [1]. Five general stages can be highlighted in the EID process [11]. Firstly, the purposes and organization of the design project must be defined. Secondly, a Work Domain Analysis is performed. The boundaries of this analysis are determined through the purposes of the project. WDA aims at describing the functional properties provided by a work environment to specify the constraints that a work system must cope with. The output of a WDA is an ontological structured model depicting a work domain as a set of functional properties classified according to their abstraction level and their position in a structural decomposition of the work domain. The WDA has demonstrated its benefits in many fields of application like medicine, aviation, nuclear plants, or network management [1]. Some of these works are themselves directly related to the development of industrial products. The third step consists in defining variables and values that concretely convey information on the work domain. The fourth step concerns the information modalities required for facilitating data visualization. Finally the last stage consists in evaluating the resulting interface prototype.

Whereas some studies have focused on the first stages of the EID process and its application to various work domains, like in medical, petrochemical, computer network, transportation, and nuclear power industry ([7]; [8] ; [9]; [10]), some others studies have focused on the last stage of evaluation. For instance, Lau and Jamieson [8]conducted an empirical study of ecological displays for the secondary subsystems of a boiling water reactor plant simulator. They used the Halden man–machine laboratory boiling water reactor (HAMBO) as experimental platform. They compared three types of display a traditional, an advanced, and an ecological display on different kinds of scenario. They showed that the ecological display provided a marked advantage for monitoring unanticipated events in a setting representative of a nuclear power plant control room with professional operators. In the same vein,Lau et *al.*[8]and Burns et *al.*[7] found that an ecological interface can support situation awareness during the monitoring of an unanticipated event for a process control task using the HAMBO.

But, if on one hand, a design process for ecological interface has been progressively defined, and on the other hand, the benefits of ecological interfaces have been validated, few researches proposed an integrated design process that ensure the obtaining of an interface that inherits from the ecological interface qualities. Only some bricks of such an integrated design process were proposed. Skilton*et al.*[15] proposed a software tool for reduced the amount of time and effort associated with a work domain analysis. Later, Burns [1] proposed a thesaurus of visual representations to assist the designer for choosing adequate visual representations. Liu *et al*. [2] also proposed a method to bridge the gap between the WDA and the design of visual representations. And more recently, Rechard*et al.*[16] proposed a method based on the Turing Machine formalism to validate and verify a work domain analysis. But to our knowledge, no integrated design tool that attempts to put together all these bricks was proposed. Such design tool would perhaps avoid that 75% of the projects initiated on the base of a work domain analysis were not completed [12], and that some currently design issues remain unsolved, likethe effect of instrumentation failure on interpreting displays [14]. It would also contribute to the optimization of time and effort in the design process [13].

2. Anaxagore, an automatic generation tool for ecological interfacedesign

2.1. Anaxagore

Anaxagore is a software able to generate a supervision interfacefrom an input diagram, [3]. Interfaces are built on the basis of a library of visual widgets and a background interface on which objects are displayed.Functional diagrams are computed as inputs for obtaining an interface prototype as output. In the first version of the software, the inputs were only information about the physical level of an industrial process. The input diagrams were a piping and an instrument diagram(P&ID). The library was composed of visual representations of physical elements linked by pipes.But, this kind of representation based on P&ID shows several drawbacks[2]:

- The functions and goals of the processes are not highlighted
- This approach of interface design forces operators to elaborate a complex mental model of the whole state of the system from single indicators displayed on the interface (the classical "Single Sensor, Single information" issue).
- This display format does not take intoaccount the operators' cognitive characteristics

Consequently, asecond version of this software has been proposedin order to produce ecological interfaces that are more ergonomics. .

2.2. Anaxagore, the software engineering in the service of EID

Anaxagore attempts at answering to several EID challenges that have been previously identified by Vicente [13]. In this set of challenges, Anaxagore offers the following functionalities:

- The formalization of the elicited work domain model: The work domain model resulting from the WDA analysis must be sufficiently detailed to tolerate an implementation in the design software. Additionally, a function of validation and verification of the work domain model is currently envisaged.
- The assistance for a collaborative design: On the basis of the diagrams translating the work domain model, the software facilitates the exchange between designers and engineers involved in the supervision interface design project. The designers of ecological interface and the engineers in charge of the instrumentations can discuss on the base of a common diagram in input. This diagram can help the designer to integrate some new criteria in the instrumentation of a technical system [18].
- The automatic translation of work domain information into visual forms: Anaxagore associates work domain information with"ecological widgets" according to the usedfunctional diagrams. This library is based on an implementation of the proposals made by Liu et al. [2] to display work domain information.This process reduces the part of art [17] in the choice of visual forms.
- A reuse engineering process: All the templates developed with Anaxagore can be stored and reused for further prototype versions in a single project or for new projects.

2.3. Anaxagore formalizes the ecological interface design

In the second version of Anaxagore, all the stages identified to design an ecological interface are refined(Figure 1). During the first stages, all the different kinds of designers(ergonomist, software, process or automation engineers) are involved to define the target and the organization of the project. The analysts and the engineersdefine the couple of input diagrams: functional and synoptic. The synoptic diagram is based on a P&ID, which provides useful low levelinformation on the industrial process. It allowsfor identifying two levels of the WDA that are the functional and physical form levels. Then,the analyst completes the functional diagramcontaining the high level information. In this step,the highest levelsof abstraction in the work domain modelare described (i.e., functional purpose, abstract function and process). The industrial process is explained by a sequence of processes. Each process is associated with some variables. These variables and the relationship between them represent the physical laws that govern the system. For example, the variables R, for resistance, and I, for intensity, and the mathematical relation RI^2correspond to the electrical law that governs the production of heat in the heater. The designer indicates the process, the variables, the mathematical relations and the sensors. During this step, the analyst can collaborate with engineers to determinate the needs in sensor for each identified variable. Finally, they jointly determine the general purposes of the system.

In the next step,the visualization of the information is generated automatically from a library of ecological graphical widgets and an interface background,using some rules on information organization. The system generates a specific representationdepending on the numbers of variables and the relationship between each variable. This representation can be a bargraph, a configural display, a meter, a trend, or a polar graphic.

Finally, the last step consistsin evaluating the quality of the interface produced by the designer team.The advantage is that it can happen very early in the process,thanks to thefast production ofanecological interface prototype. Then, if needed, the designer can redesign the interface.

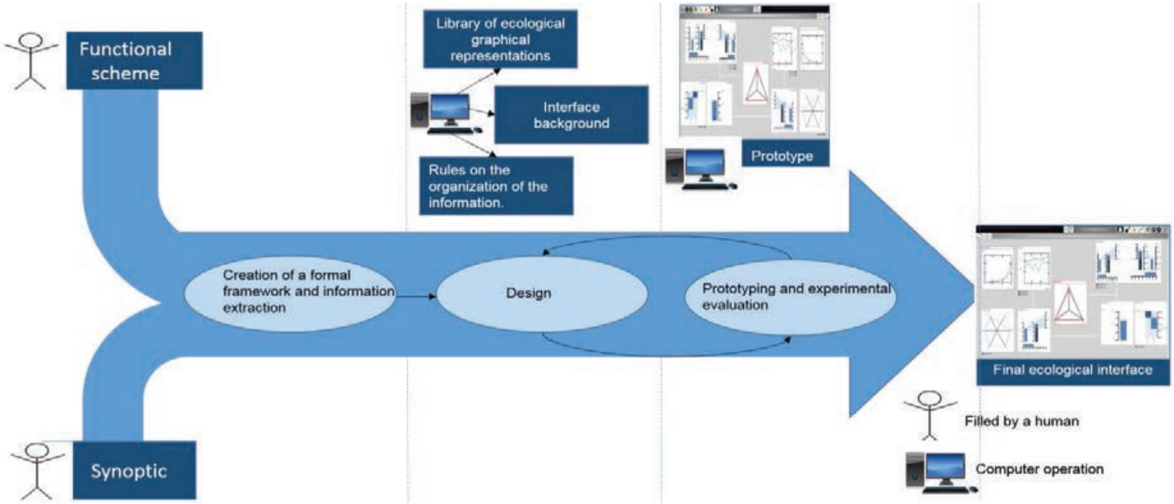

Figure 1 : Anaxagore design flow

Anaxagore could be an industrial catalyzer for the ecological approach. Nevertheless, the generated interface has to be verified and validated to ensure that itcan be considered as “ecological”. Therefore, to validate this process, an experimental protocol has been established. Twoexperimental supervision interfaces (EID and conventional) for a ship sanitary fresh water distribution systemwere designed with the help of Anaxagore. The comparison is then more robust because it is generated by the same process: Anaxagore.

3. Methodology

3.1. Experiment

The experiment was conducted at the National Maritime College, with 14 naval officers randomly divided into two groups. One group used the ecological interface (Figure 3) and the other the "conventional" one (Figure 2). The ecological interface was composed of 2 high level displays and one low level display. The conventional one was constituted by a P&ID display. All information was displayed on two screens.During one hour, each officer has been previously trained to the system and the interface used.

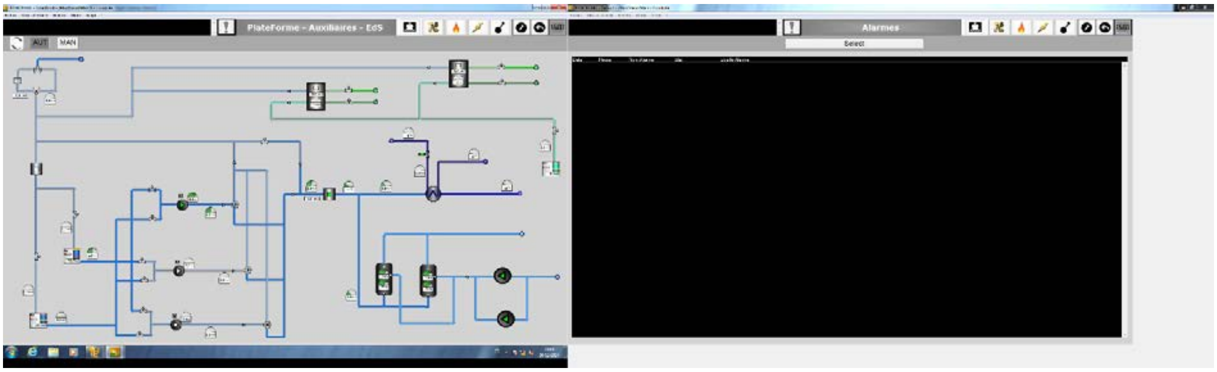

Figure 2 : Conventional interface with the screen alarm for a fresh water system

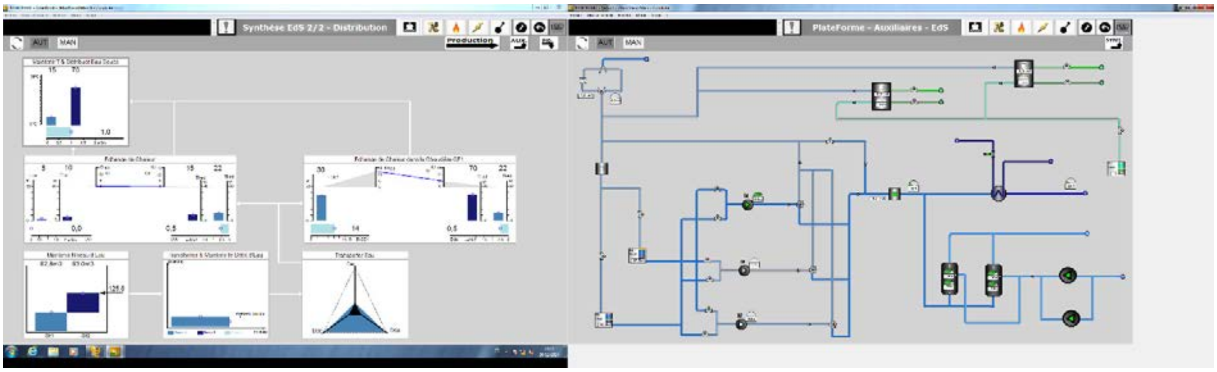

Figure 3 : Ecological interface for a fresh water system

3.2. Scenarios

During the experiment, four scenarios were simulated. The first one consisted in a strong output flowandnone input flow into the tank which feeds the distribution system, consequently the level of the tank gets down dangerously, the second one consisted in a leak on a tank. The third was a problem with the cooling system, the fresh water was no longer cooled. And the last one consisted inthe detection of a problem with the head valve of the tank 1. The valve sensor appeared open on the interface but was in reality closed. It has been requested to officers to ensure the proper functioning of fresh water system by anticipating any abnormalities. During the scenario, we asked them to verbalize their thoughts.

3.3. Measures

For each scenario, the performance was evaluated by a success score using a scale from 0 to 3, and by the measureof the time ofdetection andunderstanding of abnormalities appearing in the scenarios. Then, at the end of each scenario,a qualitative study was performed through several questions.This diagnosis was scored according to an ordinal scale introduced by Pawlak and Vicente [19].

0- The operators says nothing to relevant to the fault
1- The operator provides a vague, but correct description of the effect of the fault.
2- The operator provides a correct statement of the specific functional impact of the fault
3- The operator provides a correct localization of the faulty component.

3.4. Hypotheses

According to the literature, a better performancewith the EID prototype generated by Anaxagore was expected compared with the conventional interface. In particular, the trial completion timewith the EID should be the shortest.

4. Results

4.1. Diagnosis accuracy

For each of the abnormal events, participants made a diagnosis of the problem verbally.

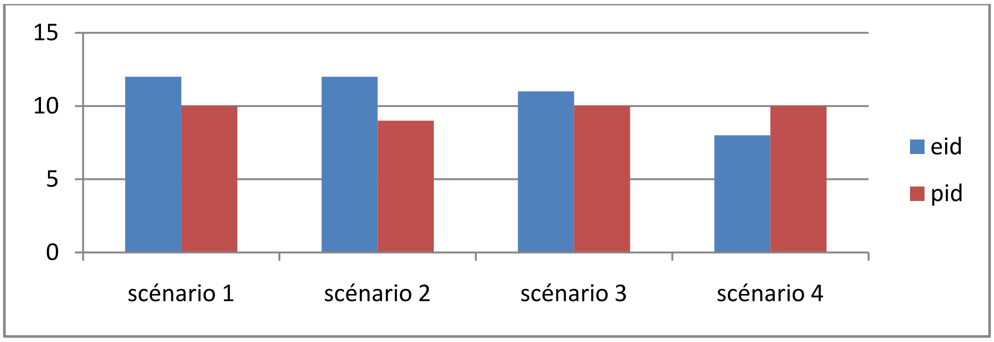

Figure 4 : Diagnosis accuracy

A Student test has been performed to compare each means. Figure 4 shows that the diagnosis accuracy was significantly better in the ecological interface condition for the scenario1 (Mean = 12 and 10; SD=0.76and 0.82; $p<0.05$), scenario 2 (Mean = 12 and 9; SD=0.76 and 0.84; $p<0.05$), scenario 3 (Mean= 11 and 10; SD=0.53 and 0.52; $p<0.05$). Nevertheless, the diagnosis accuracy was significantly better in the conventional interface for the scenario 4 (Mean= 10 and 8; SD= 0.9 and 0.82; $p<0.05$).

4.2. Trial completion time

The trial completion time was measured in each scenario. Two kinds of completion time were recorded.A first time was recordedwhen the operator provided a correct description of the fault (detection of a problem) and the second one when the operatorunderstood the problem. The participants were trained to detect and fix the problem in the shortest time as possible, regardless the event was anticipated or unanticipated. Thus, the faster trial completion times were associated with better performance. Figure 5 shows that the trial completion time to detect a problem was significantly faster in the ecological interface condition for the scenario 1 (Mean = 85secand202sec;SD=45 and 128; $p<0.05$) and 3 (Mean = 117secand192sec; SD=116 and 147;$p<0.10$). For the two others scenarios, the difference was not significant. With regards to the time to understand the origin of the problem, differenceswere not significant for each scenario.

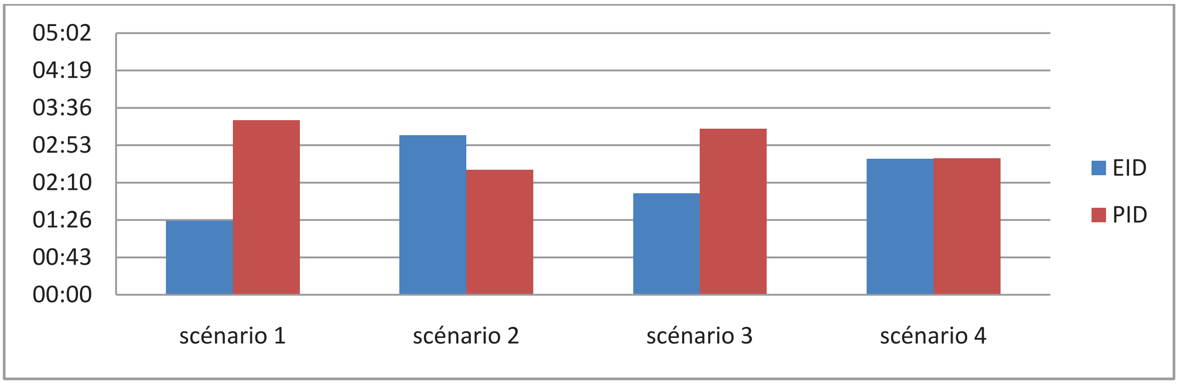

Figure 5 : Average problem detection time

5. Discuss

These first results are promising for several reasons. First, with EID produced with the help of Anaxagore,the diagnosis accuracy is betterduring the scenario 1, 2, and 3. This result isconsistent with earlier studies on EID. Additionally,the trial completion time to detect a problem for the scenarios 1 and 3is significantly shorter for the ecological interface.These results are in accordance with the experiments reported by Burns[1].

The qualitativefindings also give good insights onthe limitations of this experiment. The first oneis about the time devoted to train the operators to the use of the ecological interface prototype. Indeed, a lot of verbalizations show a lack of mastering on the ecological widgets. So, the trial completion time and the diagnosis accuracy would be better if the operator would be trained longerfor the understanding of the ecological widgets.

Moreover, the accuracy diagnosis for the scenario 4 is significantly in favor of the conventional interface. This result is not in accordance with our hypothesis. During the experiment, verbalizations show clearly that a good comprehension of the physical layout of the process is necessary to solve this scenario. Since the conventional display is based on the physical aspects of the circuit,this interface would specifically facilitate the solving of this scenario.

The ecological interface is better in the diagnosis accuracy for the scenario 2. Nevertheless, the time to detect the anomaly is not significantly different to the conventional interface. This result could be due tothe ecological widgetproperties and to the lack of sufficient training. The detection of abnormalitywasbased on the detection of a decrease in the water level in the tank. So, for the two interfaces, the abnormality can only be detected with an analogical information on the water level(Figure 6). In the EID, it could also be detected by the decrease in height of the blue rectangle. Nevertheless, the height of the blue rectangle decreased too slowly in the case of a little leak,as in the scenario 2.

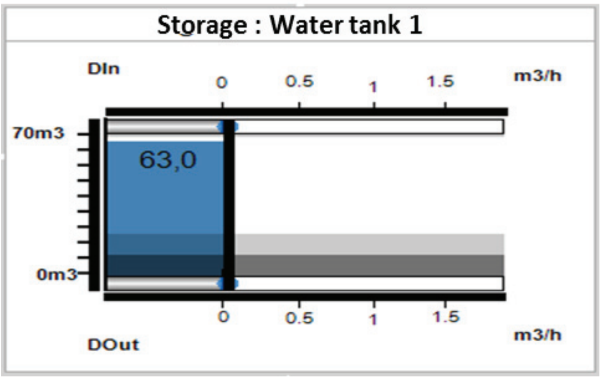

Figure 6 : Ecological widget for the storage of the water in a tank

Finally, the trial completion time to understand a problem was not significant for each scenario. The main explanation certainlyinvolves a spatial integration problem. Anaxagore generates some high level and low level displays. Nevertheless, the high level information and low information were displayed on two different screens. The time to integrate the information between them was consequently high because of the low spatial integration.Moreover, to guarantee the availability of all information needed for an EID a lot of sensors has been add in the process. Another experiment could be realized to test the EID validity with a lowest level of instrumentation.

6. Conclusion

Our results show an improvementintheoperator’s performance when an ecological interfaces prototype generated by Anaxagore is used. These results are in accordance withexperiments on EID conducted in the literature. Therefore, they support the idea that Anaxagore is an interesting tool to generateefficient interface prototypes. Furthermore, by designing rapidly ecological interfaces for supervision, Anaxagore enable to createearlyinterface prototypesfor supervision of different kinds of processes (e.g., electrical, gas process, etc.)

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