Adaptive User Interface for Process Control based on Multi-Agent approach

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ABSTRACT

Teams of operators are required to monitor and control complex real-time processes. Process information comes from different sources and is often displayed by existing User Interfaces using a variety of visual and auditory forms and compressed into narrow time-windows. Most presentation modalities are fixed during interface design and are not capable of adaptation during system operation. The operators alone must provide the flexibility required in order to deal with difficult and unplanned situations.

This paper presents an innovative Auto-Adaptive Multimedia Interface (AAMI) architecture, based on Intelligent Agent collaboration, designed to overcome the above drawbacks. The use of this technology should speed up the design and the implementation of human-centred multimedia interfaces, and significantly enhance their usability.

The proposed architecture separates generic knowledge about adaptive user interface management from application specific knowledge in order to provide a generic framework suitable to be customised to different application domains.

Benefits from the AAMI approach are evaluated by developing two industrial field-test application including Electrical Network Management and Thermal Plant Supervision system.

The paper reports the architecture and the basic design principles of the generic framework as well details of the two applications.

The work is being carried out within the European ESPRIT project: AMEBICA .

Keywords

Adaptive Interfaces, Multimedia, HCI, Agent Technology

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1. INTRODUCTION

"Adaptive systems are systems which can alter aspects of their structure, functionality or interface in order to accommodate the differing needs of individuals or groups of users and the changing needs of users over time" [BEN87]. Such an approach will assist the operator in acquiring the most salient information in any particular context, in the best form and at the most appropriate time. Without an adaptive approach the operator is working in an inefficient way, "hunting" for the correct information.

In recent years, the role of operators in dynamic control and supervision system has become more complex. The operator is now required to minimise the mean time between upsets rather than minimising the mean time between component failures. To do this the operator needs a much higher level view of the plant processes. This can partially be achieved by training, but because of the inherent complexity of modern systems much more is now required from the designer of the plant through the provision of more intelligent advice and higher quality presentation. Furthermore, the designer cannot anticipate all likely scenarios during system disturbances. The possibility to highly improve interface performances thus requires a form of interface design that incorporates adaptable elements in the way information is presented.

2. INDUSTRIAL NEEDS

Control systems are getting more and more complex. Highly sophisticated additional functionality is being continuously added to these systems, leading to an increasing level of complexity. At the same time, the problem of adapting the interface to different situations and to the operator's response has not being dealt with properly. Control system, generally, always respond in the same way without regard as to whether the flow of information is low or extremely high, or that the level of expertise of the user is good or bad.

The evolution of computer interfaces, and particularly the interfaces of critical control systems, should not add more complexity, in fact the contrary should be true, they should be easy to understand and use. The systems may continue to behave "normally" if the situation is "normal", but they should take into account all the problems that may arise, both in the controlled process and in the reaction of the operators. The control system needs to respond "consistently" and never interfere with the operator, but it should also present the operator with the most salient information in the "best" possible way.

When designing a supervision system, the designer establishes the form each type of information should take when being rendered at the interface i.e. establishes the information mapping. Operators usually have little or no choice with regard to which media is involved, when the information arrives, and how it is displayed.

This design-time mapping is not the only possible one, but it is considered the most effective or efficient. Other possible mappings are rejected during the design process. No matter how good the design based mapping is, it has the disadvantage of being fixed or static.

We can list the following disadvantages of the traditional approach in MMI design:

1. The information is presented in a rigid structure.
2. MMI's are not designed for emergency situations where the information rate is too high and operators have to face new situations.
3. The information is not ordered according to priority.
4. Navigation is difficult through complex interfaces.
5. Technical information is not included.

It would clearly be desirable if it were possible to have not just one mapping but a set of mappings, from which the most appropriate could be selected at any given time and for any given conditions. Within the described work, these drawbacks were considered with reference to two field-test applications: Electrical Network Management (ENM) and Thermal Power Plant Supervision (TPP).

2.1 Application requirements

2.1.1 Adaptation triggering

A set of conditions for starting the adaptation, called "**initiating event**", have been defined depending on:

- **Process deviation.** When the controlled process moves from a normal status to a disturbed status the operator can often be stressed by the huge amount of alarms generated. Interface adaptation should help the operator identify the problem and solve it. In this case adaptation should prevent the operator losing control of the situation
- **Operator deviation.** This happens when the operator does not understand the problem correctly, and does not react according to the expected procedure. Although quite difficult to detect, this event should be quite useful as a means of initiating appropriate interface adaptation with the goal of highlighting the problem and suggesting the correct interventions.

2.1.2 Adaptation effects

The main expected result of adaptation is to organise the interface in order to present the information in the best possible way according to the current process and operator status. Some actions that can be undertaken to achieve that goal are:

- **Highlight relevant information.** The importance of incoming information depends on the actual "scenario". Adaptation should dynamically detect the most pertinent and relevant information and should manipulate the display parameters to highlight it.
- **Optimise space usage.** The display space organisation should be adapted and optimised according to the current "scenario".
- **Select best representation.** Incoming information can be displayed by using a set of alternative modalities selected on the basis of the current "scenario" and of the interface status.
- **Consider time.** The above adaptation action should follow the evolution of the "scenario" over time.

3. STATE OF THE ART

3.1 Adaptive Multimedia Interfaces

Artificial Intelligence (AI) techniques are powerful when actions must be decided upon and taken in the context of a consistent and monotonic world. In an industrial scenario such as our proposed industrial application, operators, system and context are continuously changing and are sometimes in contradiction with each other. Thus, any such multimedia interfaces should achieve a balance between these three components and be flexible enough to adapt consequently to a change in the relative importance of each of these three components. In such approach we have to consider adaptation driven by the process and adaptation relative to the user. As exposed in [HOR99], a mixed-initiative user interface approach should be favoured where "from the perspective of decision theory, decisions about action versus inaction should be directed by *expected utility*" and "autonomous actions should be taken when an agent believes that they will have greater expected value than inaction for the user". Our approach considers that such an interface can be designed and implemented more easily by the use of techniques that come from Multi-Agent Systems (MAS) technology.

3.2 Multi-Agent Systems

Agents are quite a natural abstraction for analysing, designing and implementing some kind of complex software systems [JW99]. Thus, agent technology is now widely used in industrial and commercial applications: manufacturing, process control, telecommunication systems, air traffic control, traffic and transportation management, information filtering and gathering, electronic commerce, business process management, entertainment and medical care [JW 98].

Precise methodologies to cast agent systems as a software engineering paradigm begin to appear [WOO 99], [JW 99]. New tools to ease the implementation of multi-agent systems are also emerging: JACK [BUS 99], the ZEUS Agent Building Toolkit of BT Laboratories' [COL98] and the BOND project at Purdue University [BÖL99] to name a few.

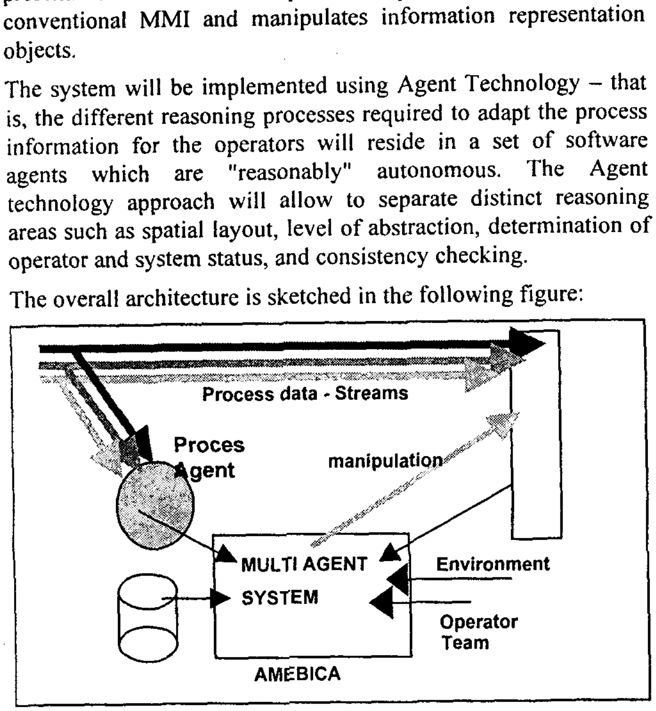
The use of agent techniques in the field of human-computer interaction is realised in projects such as Letizia [LETI], an agent that assists a user browsing the World Wide Web and which is representative of the Interface Agent area. In this paper, a design solution considers the emergent behaviour of a collection of active design agents, each of which is responsible for the presentation of a particular element of information [CRA98] expose some of the ideas on which the AMEBICA project is based.

4. CONCEPTUAL DESIGN

At the heart of our design is the notion of adapting the presentation of information by selecting and manipulating presentation modalities. Adaptation loop acts in parallel with a conventional MMI and manipulates information representation objects.

The system will be implemented using Agent Technology – that is, the different reasoning processes required to adapt the process information for the operators will reside in a set of software agents which are "reasonably" autonomous. The Agent technology approach will allow to separate distinct reasoning areas such as spatial layout, level of abstraction, determination of operator and system status, and consistency checking.

The overall architecture is sketched in the following figure:



4.1 The Stream Concept.

Process values arrive in continuous *streams* and these are rendered at the interface usually in some standard graphical form. The AMEBICA adaptive system does not operate on the streams as they pass through to the rendering system, but operates through its reasoning processes on the set of representations in the Interface. With this indirect coupling approach, the operator receives information *on-the-fly* in a timely manner, only then does AMEBICA modify the renderings as a result of its reasoning processes.

4.2 The Generality Principle

AMEBICA aims to be a generic adaptation system that maps events of discrete levels of significance - at the input - to appropriate rendering characteristics at the output. To achieve this, no direct process knowledge is embedded within AMEBICA. Rather, AMEBICA has two interfaces – the Process Model Agent and the Abstract Rendering Interface - that allow it to interact with its environment. The Process Model identifies domain specific occurrences in the operator or system environments and triggers AMEBICA. The Abstract Rendering Interface takes general commands from AMEBICA and renders them in domain dependent representations.

4.3 Spatial Adaptation Principle

There is some empirical evidence that operators have certain cognitive traits that are resistant to change, and hence are particularly important for adaptive systems. Spatial ability is one such characteristic and one which AMEBICA aims to provide adaptation for, especially in terms of making it easier for the operator to realize where salient information is. However it is also important to maintain spatial consistency during adaptation, so to avoid confusing operator instead of helping him.

4.4 Flexible Mapping

In traditional interfaces, a mapping is made at *design time* between the process parameters and appropriate renderings at the interface. This mapping is usually the best all-purpose mapping under a set of general constraints. Within AMEBICA we hold a set of possible mappings, and the set of constraints which make one mapping more appropriate than another does in a given context. When the process moves into a disturbed state, the most suitable mapping is selected for the undergoing scenario, and is dynamically updated or changed to follow the scenario development. AMEBICA performs this flexible mapping based on the current state of process, the environment, its model of the operator and its knowledge of human factors.

4.5 Operator based adaptation

A main issue in an adaptive system is the identification of conditions for triggering the adaptive functions. AMEBICA is aimed at a joint human-machine system; thus it makes sense to consider deviations related either to the human and the machine, i.e., the process. These deviations should be derived from measurable states, parameters or action.

Process Status: In the case of the state of the process, it is clearly possible to identify a set of distinct system states and to associate these with specific patterns of measurements.

Operator Status: In the case of the state of the operator or user, the situation is more difficult. While it makes sense to refer to specific states of the user, such as being attentive or inattentive, it is very difficult to find on-line measurements that can be used to identify these. Within AMEBICA the only measures considered are those that can be derived directly from the operator's actions.

These objective measurements are used to estimate the operator status according to simple HCI rules. A matrix describes possible states and applicable adaptation actions:

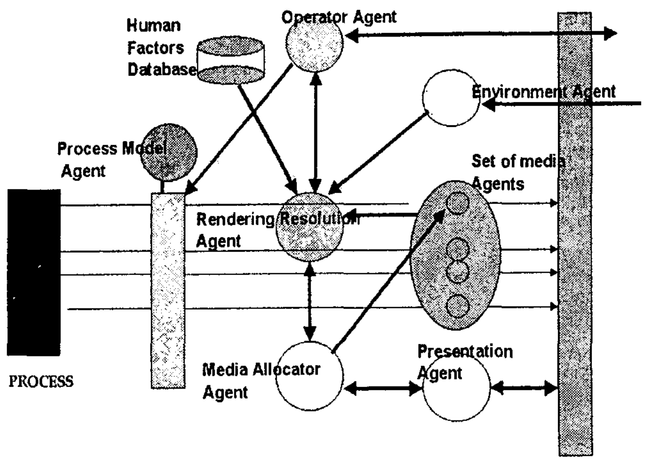
Operator response	Process status normal	Process state disturbed, high information rate	Process state disturbed, low information rate
Normal	OK Process triggering only	OK Process. triggering only	OK Process triggering only
Delayed (relative to expected responses)	(1) Inattentive: Accentuate presentation	(4) Overloaded. Filter information, simplify presentation	(7) "Frozen". Repeat recent information. Try alternat representation
Erratic (occasionally wrong display or commands)	(2) Inattentive. Accentuate presentation (specific)	(5) Overloaded. Simplify displays, remove informatio	(8) Partial loss of comprehension. Switch modality
Disorganised (constantly wrong display or commends)	(3) Confused, loss of control. Go to overview presentation	(6) Severe loss of control. "Voice of god"	(9) Complete loss of comprehension. Go one level up, summarise info.

This matrix is mainly a conceptual tool and its real use in the project is not straightforward due to the difficulty of obtaining a reliable estimation of operator status.

5. MULTI-AGENT ARCHITECTURE

5.1 Architectural Description

The following figure illustrates the main components of the architecture; their main functions are described below.



Process Model Agent: To monitor and act on process information using its knowledge of the process to translate system dependent calls to AMEBICA calls.

Media Agent: Responsible for the rendering of a stream of process information. It contains within possible design time mappings, the most appropriate of which is selected at runtime by AMEBICA.

Rendering Resolution Agent: Interacts with *Human Factors Database, Environmental Agent* and *Operator Agent* to decide upon the best renderings for a certain situation.

Environmental Agent: Captures information on the current environmental conditions in the control room.

Human Factors Database: A set of key HCI heuristics used to help decide the most appropriate rendering.

Presentation Agent: The Presentation Agent has a continuously updated view of resource usage on the interface in all media.

Media Allocator Agent: The Media Allocator makes the final decision on the choice of rendering, which it returns to the *Media Agent.* It bases its decision on interactions with the *Presentation Agent.*

Operator Agent: Monitors and logs the operators actions, for instance mouse clicks, and keyboard operation.

6. PROTOTYPES

Two prototypes are under development with the project. They apply to the Electrical Network Management field and to Thermal Power Plant supervision.

AMEBICA framework has been customised to include specific application knowledge for interface object management based on process status and incoming events. A set of information display object was developed for these specific applications.

Main achievements shown by these two prototypes so far are:

The operator could verify instantly, without even interacting with the system, what has happened in the field, immediately accessing all the information they require. The operator could maintain a holistic view of the process status, while being able to view, at the same time, the detailed information they require to co-ordinate the maintenance teams.

7. CONCLUSIONS

Supervision and control systems provide an increasing amount of information in a reduced space and are unable to change the presentation modality according to the current context. The operator has to provide additional flexibility to deal with difficult and unplanned situations in order to preserve system efficiency. The AMEBICA project tries to overcome these drawbacks by developing an Auto-Adaptive Multimedia Interface approach. It is based on collaborative agents and provides a flexible mapping between process data and MMI objects. This flexible mapping allows AMEBICA to dynamically select during operation the best representation from a set of predefined ones.

The final result of the adaptation will depend not only on process conditions but also on other factors such as operator's responses and actions, the type of information presented to the operator, the environment conditions and human factors.

A general-purpose framework has been described that provides generic adaptation capabilities to be customised for realisation in industrial applications. The framework is evaluated by two test-field applications for Electrical Network Management and Thermal Power Plant Supervision.

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