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Improving digital interaction for operator-driven process-plant operation

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Abstract: Operating process plants to control, maintain and manage them remains a complex activity driven by skilled operators. Despite the increasing capabilities of automation and information technologies, only a part of the technical objects of a process plant digitally interact with human beings when performing their tasks. This paper presents preliminary work based on the *Ambient Intelligence* concept in order to improve the digital interaction between human beings and technical devices when sharing common activities. Copyright©2008 IFAC

Keywords: Process Plant Operation, Ambient Intelligence, SysML, Simulation, Modelica

1. INTRODUCTION

In industry, physical systems have become more and more complicated due to the multitude of components and their sizes. Thus they became more difficult to control, to survey and to maintain. For security reasons, we have to be capable of predicting their behavior in all situations, and for all possible environmental perturbations. This is a difficult task and solutions are needed to improve the security and the dependability, to prevent serious accidents due to the incomplete understanding of the complex system.

Solutions based on active components are available, transforming instrumented components in components with a reactive behavior. In spite of these advances we are still dealing with non-resolved problems of non-instrumented components.

The technological evolution and the microcontroller miniaturization have created new concepts like ubiquitous computing (the expanding of microcontrollers in everyday objects). Ambient Intelligence concept relies on ubiquitous computing in order to help people to accomplish their activities, being assisted by the surrounding environment itself.

Ambient Intelligence brings new visions in industrial applications which are based on permanent human to system interactions.

This article discusses preliminary results obtained using Ambient Intelligence concept in operating process plants. This work is motivated by the difficulties encountered in the process of controlling a complex system, considering as example a nuclear power plant.

The problem statement and the motivations will be presented in section 2. Section 3 deals with a brief introduc-

tion to Ambient Intelligence, stressing its main advantages. A discussion of the results is provided before to conclude.

2. MOTIVATION

Recently, the exchange of knowledge and information between different actors of a production plant has become a necessary ingredient in complex systems' control and maintenance. An integrated organization requires that information from the process is made available for common use by the Control, Maintenance and technical Management (CMM) activities.

In 1998, Pétin et al. (1998) proposed a solution to integrate the "intelligence" into a physical system, especially for instrumented components. They present a distributed Intelligent Actuation and Measurement (IAM) system that helps in providing an informational representation of the production process as efficiently as is possible. This representation is distributed through field-bus architecture to all integrated activities of CMM.

The intelligent actuator representation (see fig. 1) incorporates four functional modules: the objective validation,

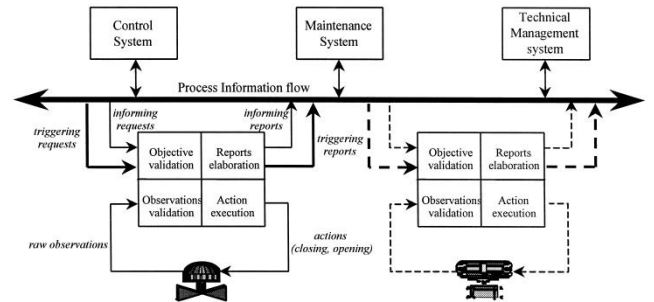


Fig. 1. Visible and interoperable architecture

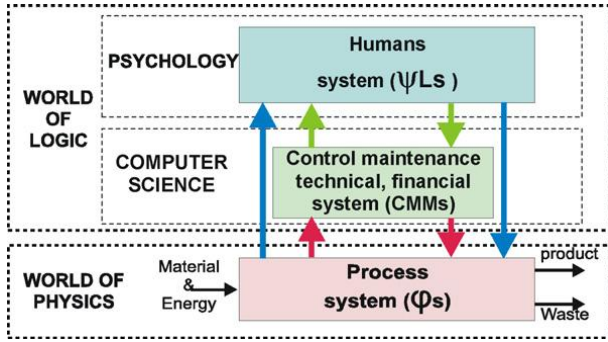


Fig. 2. Plant operation: a complex system (Galara (2006))

the report elaboration, the observation validation and the action execution. This solution is already implemented in industry and there are companies that propose it (i.e. PREDICT France). However, it applies only to the instrumented components (about 20% in case of a nuclear power plant). Our research problem is related to the non-instrumented components.

It would be incensed to consider that the physical system associated to a Nuclear Power Plant (NPP) can be non-deterministic. The complexity of a NPP resides mainly on human to physical system interaction. Therefore, this system can become not only complex, but also non-deterministic.

This issue is illustrated by Galara (2006). He proposed an explicit representation of the plant operation in order to help operators to improve safety, productivity and reduce environmental impact. Considering the plant operation as a complex system, Galara considers the NPP control as a system-of-systems (see fig. 2):

- The world of physics is a set of interconnected field technological devices supporting transformations of primary energy and material into products and wastes: the physical system (φ_s);
- The computer science, also called "abstract layer", is a set of interconnected automata: Control, Maintenance, technical and financial Management system (CMMs);
- The psychological layer is the human organization and information processing (Ψ Ls).

Therefore, considering this representation as a basis for our work, we tried to describe and offer solutions to plant operation problems.

The process layer (φ_s) is composed by all physical components of a NPP, counting more than 10.000 components to be controlled. A general problem is that about 80% of components are non-instrumented (without actuators or sensors), mainly due to cost and communication problems (cables).

The human organization layer (Ψ Ls) is composed by a hierarchy of personnel working in the NPP. Two categories can be distinguished: the Control Room Operators (CRO) and the Field Operators (FO). The CRO controls, at distance, not only the systems' components but also the FOs' actions. The FO work within the physical system and controls all non-instrumented components. This system is

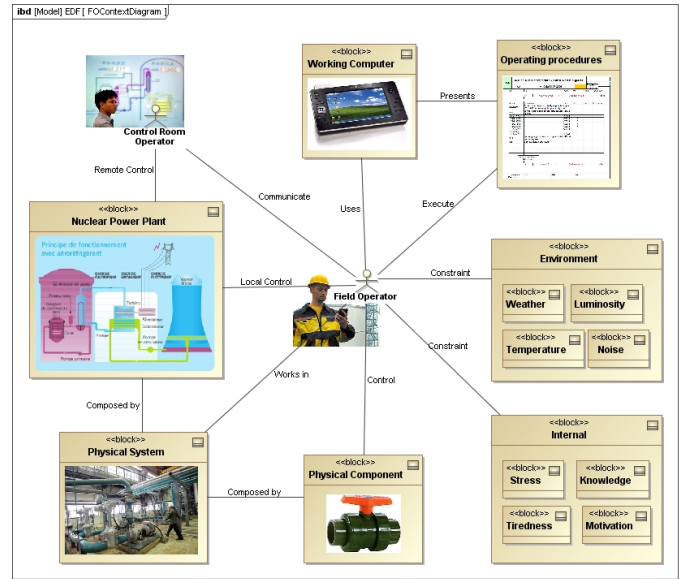


Fig. 3. Field operator's working context

studied by the Cognitive Systems Engineering or Human Factors Engineering.

The Control, Maintenance, technical and financial Management system (CMMs) is composed by all means used to make a NPP work. There are control operations, maintenance operations, financial operations, etc. Our research objectives are related to this system, and more particular to complex systems control. In the next paragraphs we describe the problems related to our research.

To control a NPP, the personnel use pre-specified procedures. These Operating Procedures (OP) are a set of operations/actions that must be executed consecutively. They are written by the design engineers who must anticipate all possible states of the process and its environment. The procedures are usually implemented in the construction step, but it is essential to evolve in time. To respond to system's complexity, a realistic plant simulation could prevent undesired events. This simulation should also take into account the entire OPs associated to each physical system, called Operating Guides (OG).

Spangler and Peters (2001) have established a framework for an explanatory model of organizational knowledge and behavior in environments where procedures are an important influence on system behavior. Their solutions to operating problems is an ontology that models the explicit knowledge structures and their interactions. They validate the model in a computer simulation that explains and predicts human interventions in real-world scenarios.

Figure 3 illustrates the FO's working context, showing interactions and constraints that influence the quality of work.

The operators' cooperation and good synchronization is a key point in controlling a nuclear power plant. To conduct a safety and reliable component manipulation the interaction between FO and CRO must be done in real-time and permanent.

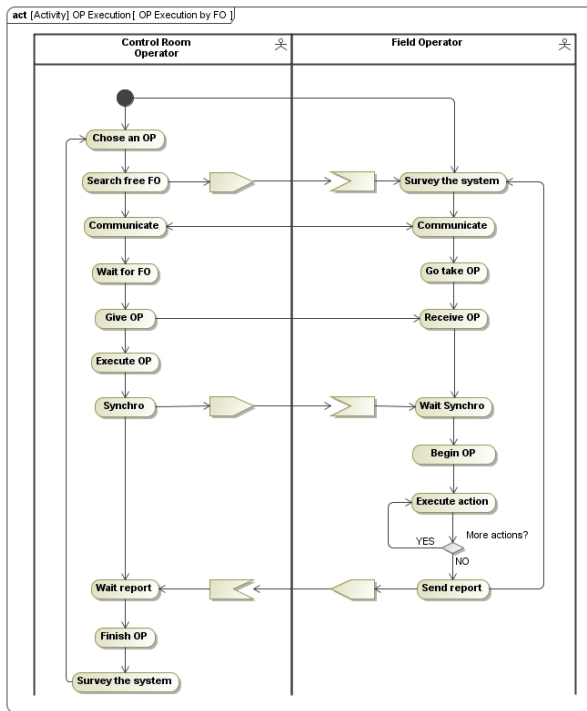


Fig. 4. OP execution by a field operator

A FO works in one physical system and controls mainly non-instrumented components. In some cases, the FO uses a portable computer to help accomplish his job, but in many cases the OP information is represented on a printed paper. The problems using printed papers are related to paper degradation due to different causes.

Moreover, the efficiency of the FO's work can be influenced by environmental constraints (like temperature, noise, whether) and internal constraints (like stress, experience, knowledge acquired during formations). These constraints can influence the quality of work and the reactions to different problems.

A step in the OP contains information about the component and the action, but it is the FO's job to locate and to identify the component, and to execute the action. However, the most important is action validation (the proper action on the right component at good moment). Nevertheless, the OP does not contain information about all possible cases. Therefore, the FO has to reorganize his work in collaboration with CRO in order to satisfy the constraints.

The activities done by the FO to execute the OPs are represented in figure 4. It is given by an activity diagram using SysML representation.

It all begins in control room where the operator chose to execute an OP. In most of cases, to accomplish an OP, the operator must collaborate with a FO. So, he searches one available. The FO, which surveys the system, stops his work and begins to communicate with the CRO. The communication is based on DECT telephone or walkie-talkie. Some communication constraints are the cable lines and the wireless link specification that could interfere with sensible devices within the systems.

Because the OPs are paper-based, the FO must go and recuperate them from Control Room (CR). So, there is a waste of time from the moment the FO begins to communicate and the moment he begins the OP execution.

The OP execution is done in two (or more if necessary) steps. First, the CRO begins to execute his list of actions. At a specified time, in order to continue, he must synchronize with the FO. The FO begins his work and at the end he will write a report that will be sent to CRO. This can take from hours to days, depending on system evolution and operator motivation. Due to this delay, we could discover some inconsistencies between the logical situation and physical situation.

These different situations are explained in Galara and Hennebicq (1999). The process is evolving from one steady-state process operation to another steady-state process operation. The situation described by the components' state can be different for the CRO and FO, as their activity can be done in serial or in parallel. The problem is how to map the physical situation into logical situation to eliminate the inconsistencies.

There are actually some works to computerize the operators in order to facilitate their work and to communicate information faster and safer. In O'Hara et al. (2004), the authors discuss the presentation of information in computer-based control rooms. Several approaches to information design are presented, specifically addressing: (1) monitoring, detection, and situation assessment; (2) routine task performance; (3) teamwork, crew coordination, collaborative work.

Pirus have done studies in using computers in field operation (Pirus (2006)). The informatics systems could respond at the difficulty of using paper documents, but must be well studied because the FO must have free hands, must allow audio and video communication, must facilitate interaction, etc.

This is why there is a necessity to find solutions in physical systems control and mainly to test new technologies and concepts that could bring new visions to this domain. Ambient Intelligence is one concept that could change the way of thinking about operators' work.

3. AMBIENT INTELLIGENCE IN WORK ENVIRONMENTS

It all started in early 1990s. The ubiquitous computing was invented by Weiser (1991). This concept refers to an environment where objects are given the information processing capability. The Ambient Intelligence is based on ubiquitous computing concept.

An Ambient Intelligence (AmI) environment is a surrounding computing space that is spontaneously and proactively supporting the user's needs (Rigole et al. (2007)). The principle (Vasilakos and Pedrycz (2006)) is to integrate different computer science backgrounds together with psychology and social sciences in order to create a network of intelligent devices (with sensors and actuators) able to enhance the quality of people life.

There are many research projects on AmI. Friedewald et al. (2007) have done scenario analysis in different applications

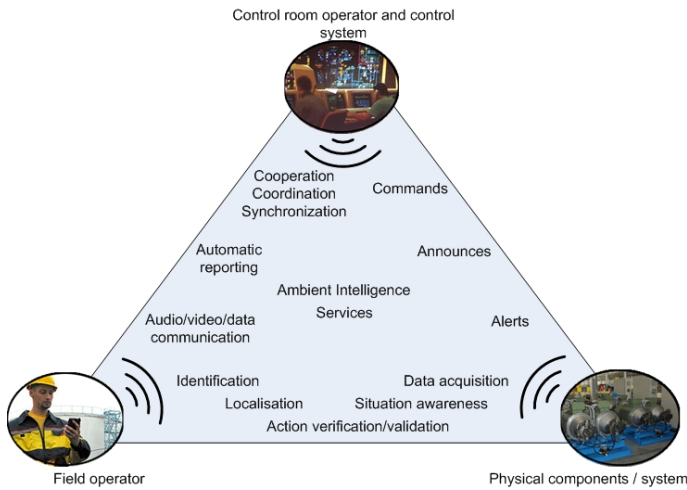


Fig. 5. Ambient Intelligence services

domains: home, work, health, shopping, mobility, leisure and entertainment. The AmI is supporting the work environment by:

- providing communication between people;
- support the mobility of workers;
- providing access to work-related information at any time and from any location, improving knowledge sharing and co-operation;
- providing efficient working tools;
- controlling diverse working appliances;
- increasing safety and security;
- domain-specific functionalities such as diagnostics of equipment, factory automation, etc.

The scenario proposed by Aarts and Roovers (2003) contains three basic AmI functions. Firstly, the environment is contextual aware, which means that there are sensors integrated into the environment which communicate events that can be combined to determine meaningful states and actions, like person identification, position detection, and query interpretation. Secondly, audio, video, and data can be streamed wirelessly to any access device present in the environment, thus enabling ubiquitous wireless access to information, communication, services, and entertainment. Thirdly, users in an Ambient Intelligent environment interact with their surrounding through natural modalities such as speech, gesture, and tactile movements, thus enabling hands free interaction with their environment.

Researches of AmI in industrial application are not very frequently. Müller and Zimmermann (2005) is studying the use of ambient technologies to solve informational problems in Process-to-Maintenance processes. The activity domain is the production, transport, installation and maintenance of machines and plants. The point of interest is the overview on ambient hardware and software technologies relevant to their domain.

Ambient Intelligence concept can help us improving human to system interaction. As we are interested more in field operator system control, we study AmI by taking him as the central actor of the system.

We can assimilate AmI to an interface between the FO and the system he controls. This interface helps him to

improve work quality by offering personalized services. In figure 5 we illustrate some services examples that could be implemented to assist operators.

We have three interactions types: CRO – FO, CRO – PS and FO – PS. The interaction between CRO and FO is done to cooperate, coordinate and synchronize their work. AmI can improve the communication between the two using audio, video and data transmission, wirelessly, anytime and everywhere. The audio transmission is used for verbal communication, video is used to send images from the system for diagnostics, and data transmission is used to transfer information like OP and additional documents about OP execution. Also, automatic reporting could reduce the report time after OP execution.

In AmI, the physical objects are given the possibility to "think" and to have a behavior of their own. Wong et al. (2002) presents five characteristics of an intelligent product:

- Possesses a unique identity;
- Is capable of communicating effectively with its environment;
- Can retain or store data about itself;
- Deploys a language to display its features, production requirements, etc.;
- Is capable of participating in or making decisions relevant to its own destiny.

Bajic (2005) add another characteristic: offers objects advanced services along its life cycle.

Using advanced technologies, like RFID and Wireless Sensor Network, we can enhance the possibilities of an ordinary object, implementing reactive behavior, and increase the security of work. Implementing services like identification and localization of a physical component could eliminate the component mistake error. Automatic data acquisition about components' state could minimize the surveillance time. Action verification and validation, done by the component itself, could assist the FO in his work and could eliminate manipulation errors. Automatic traceability will help and improve the maintenance process. The situation awareness could eliminate the incoherences between the physical situation and the logical situation. All these services are intended to be transparent to the FO and used by natural ways.

4. SYSTEM ENGINEERING FOR COMPLEX SYSTEMS

In our research we have chosen to adopt the System Engineering project life-cycle. This article presents some of our results: the problem state model and the simulation of a physical system. The simulation recreates the scale factor of a real physical system. The modeling part is made using SysML. The simulation has been implemented using Modelica language.

4.1 Modeling Complex Systems: System Engineering

SysML¹ is a UML2 profile that customizes the industry standard for modeling software-intensive systems for sys-

¹ OMG SysML - www.omgsysml.org

tems engineering requirements. It supports the specification, analysis, design, verification and validation of a broad range of systems and systems-of-systems. These systems may include hardware, software, information, processes, personnel, and facilities.

In System Engineering, the project development is realized using the V cycle, starting with system's requirements analysis. There are User Requirements and Functional Requirements. The User Requirements are requirements given by the final user: to improve the operators work in controlling physical components. From these requirements and from the environment study we can extract the Functional Requirements.

After the requirement analysis, we have modeled the physical system on which we will test our concepts. It is a hydrodynamic installation containing all kind of components, instrumented and not instrumented.

First we have implemented a taxonomy classification for all physical components we are using in our system. Using these components, we implemented the technical infrastructure by instantiation. The technical infrastructure helps us to oversee the dimensions and parameters for each component. In parallel with the model we have worked on system simulation.

Using SysML we have modeled the OPs related to our system. They are implemented using Activities Diagrams. The OPs set forms the Operating Guide, implemented as a Block Definition Diagram.

4.2 Simulating Complex Systems: Modelica

The Modelica² language is widely used in industry for modeling and simulation of physical systems. Example application areas include industrial robotics, automotive applications and power plants. Typical for models of such systems is that they are of large scale, commonly up to 100.000 equations. There are also extensive standard libraries for e.g., mechanical, electrical, and thermal models.

The primary objective of formulating a model of a complex physical system is most often simulation. That is, prediction of the response of a model, given a specified input stimuli, and the state of the model. If the model is sufficiently accurate, the simulation results may be used to draw conclusions about the behavior of the true physical system (Åkesson (2007)).

The ModelicaML unified language for modeling and simulation of complex systems combining both SysML and Modelica is the work of Pop et al. (2007). The profile combines the major UML diagrams with Modelica graphic connection diagrams and is based on the SysML profile. The new diagrams introduced in ModelicaML are the **Equation Diagram**, under Behavior Diagram, and the **Simulation Diagram**.

The environment used for creating and simulating Modelica is Dymola. Using Modelica Fluid library we have created a hydrodynamic system. In figure 6 we show our model. It is based on a real physical system that is intended to be installed in order to test all proposed concepts and

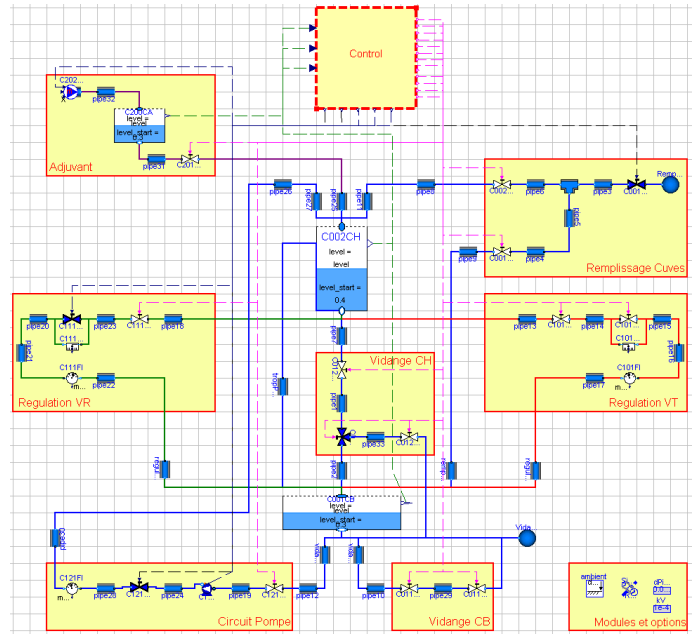


Fig. 6. Modelica model for simulation

technologies. In order to model and to verify the good construction of the platform we have chosen to simulate it using Modelica. Also, we can verify and validate the OPs' coherence of action execution.

Because the Modelica language supports both physical equation and algorithmic procedures, the combination of the two allows to create multi-domain models and simulations. The physical system is described using different equations. In addition, we can implement algorithmic entities to simulate technologies like WSN or RFID, even to implement different AmI services.

A multi-domain simulation involves some requirements to be fulfilled. First of all, there are lots of objects from different domains, like hydrodynamic, networking, automatic control, etc. An object oriented simulation environment like Modelica allows the reuse of components. Furthermore, it is an open language and there are lots of free libraries.

To visualize system's behavior, the environment must allow the real-time simulation. With Modelica this is possible using the Dymola real-time option or using the free real-time library from Wagner and Frey (2007).

Another useful feature for a simulating environment is the reuse of libraries and code used in programming real objects. In Dymola it is possible to use C and Java code and to bypass any limitation given by Modelica language.

Last but not least, the simulation environment must permit the interaction with components, to change states and to receive situations. Olsson (2005) presents some of the possible interfaces to Modelica using Dymola. Besides external C/Java code that can implement any socket communication, there is the possibility to interact from Matlab or using any application with DDE (Dynamic Data Exchange).

Ambient Intelligence is described by an environment where objects have capacities to react to changes and to commu-

² Modelica Association - www.modelica.org

nicate with each other and with peoples. We can simulate such environments with Modelica by creating behavioral objects and enabling any user to interact with virtual simulated physical components.

5. CONCLUSION

This article describes preliminary results on our research, concerning the problems of controlling complex systems. Complex systems are very large systems where the number of elements implies costs and communications issues. In such systems, the good communication, coordination and synchronization of working personnel is essential to conduct a safety and reliable system manipulation.

Ambient Intelligence describes an environment in which the human is assisted by the surroundings and manipulated objects to improve his work. Using advanced technologies and personalized services, we could enhance the interactions between operator and the system he controls. We have given some service examples like localization, identification and transparent action verification and validation.

The first results of this work are mainly situated in the modeling and simulation step. For modeling we have chosen to use the System Engineering process and for the complex system model, SysML is the most appropriate modeling language. For the simulation we have used Modelica, an object oriented language for modeling and simulation of large physical systems.

Our approach based on Ambient Intelligence can improve the digital interaction between human beings and technical devices when sharing common activities. Using System Engineering project process we can model advanced systems and with Modelica we can verify the correctness and the feasibility of modeled systems.

The next step in our research is to implement different Ambient Intelligence services within Modelica simulation. This will allow us to verify the feasibility of using such concepts. One issue will be the possibility to recover the implemented services to external computers and to test the interactions between the FO and the system by using advanced services.

The most important step will be the construction and implementation of these services using advanced technologies on the physical platform itself.

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