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Improving Human-System Digital Interaction for Industrial System Control: Some Systems Engineering Issues

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Abstract: In industrial system control, the human-system interaction represents one of the challenges, especially from the field operator's point of view. This interaction is usually guided by procedures. Nevertheless, the adage "error is human" is mainly confirmed in support phases such as maintenance, generally during shutdown and restarting phases. The solution proposed in this paper is to enhance the digital capabilities of the field operator in order to better balance the role distribution between the system and the human. Engineering this human-system interaction as a whole requires formal methodologies in order to define, develop and deploy digital solutions distributed over the technical system and the human operator, seen together as a unique socio-technical system. Ambient paradigm, infotronics technologies, as well as SysML modelling language are the key elements employed herein in order to improve the digital human-system interaction for industrial system control. Copyright ©2010 IFAC

Keywords: Process Plant Operation, Human-System Interaction, SysML, Specification

1. INTRODUCTION

Galara emphasizes in his "roadmap to master the complexity of process operation" (Galara (2006)) the main issues concerning non-nominal operating phases like shutdown and restart in industrial systems operation, mainly power plants. These common causes of failures are particularly attributed to the difficulty encountered by the operators to cope with unfamiliar situations, and more precisely to an inadequate role distribution between the human operator and the technical system. For this reason Galara proposes to adjust the process control language semantics as it is the joint support for the control room operator and Field Operator (FO) in control situations.

In other words, the actuation and measurement systems must "disappear" from the FO's focus, as its attention must be centred on the process control and not on the instrumentation control. Conversely, the process must be "protected" with respect to control actions that may deteriorate or even cause dangerous situations. In this sense, the "LABIME" language (fr. LAngage d'expression des Besoins en Informations des Mtiers d'Exploitation) proposed by Galara et al. (2008) is based on process behaviour formalization using logical expressions to facilitate its understanding while banning forbidden actions.

This context highlights the need to enhance the digital interaction between human operators and the technical system, as expressed within the research community by Baptiste et al. (2007).

Herein, we propose a solution for the interaction between human and technical system. The problem is stated in

section 2, as well as a reference model for requirement and specification of socio-technical systems. For engineering purposes, the "specification" concept is included in a SysML extension, as presented in section 3. Section 4 gives specifications for the human to technical system digital interaction: the digitalization of the technical system and the digitalization of the human system. Section 5 presents technological elements used to prototype such an improved interaction.

2. PROBLEM STATEMENT

Previous works have shown, in major european programs, the interest to distribute within the process a form of "technical intelligence" organized around a field bus: intelligent actuation and measurement systems (IAMS) and an integrated system of control, maintenance and technical management (CMMS) (Fig. 1) (Pétin et al. (1998)).

In a more general way, Zaremba and Morel (2003) addressed that the intelligence in manufacturing is generating a considerable amount of interest occasionally verging on controversy within both the research community and the industrial sector. This is particularly true when overlapping the engineering of technical systems to the engineering of mind, as addressed by Albus (1999), in order to propose a reference model architecture for intelligent systems.

Considering a production plant, such solutions only concern the instrumented components. However, an acknowledged issue within a power plant is the large number of non-instrumented components which are manipulated by the FO in supporting phases. Because these components

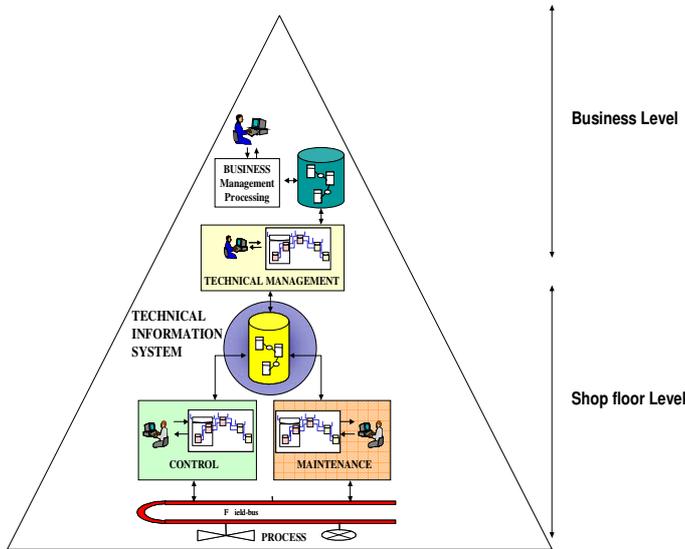


Fig. 1. Integrated Control, Maintenance, and Technical Management based on Intelligent Actuation and Measurement Systems

are unobservable and uncontrollable, the human-system interaction supposes to study first the problem of the balance between the technical intelligence of components and the human intelligence of operator, and then the engineering of this interaction.

This paper proposes to improve this interaction with non-instrumented components by digitalizing it.

Digitalizing the human-system relationships is another challenge of intelligence in manufacturing by considering the human as a component of a socio-technical system. The requirements analysis model (Fig. 2) proposed by Hall and Rapanotti (2005) extends the original model proposed by Gunter et al. (2000) in order to add the human area (H) to the previous area related to the relevant environment (W) and the target machine (M).

A basic principle in this framework for systems engineering issues is that the specification S mediates between

- the *problem space* W of the contracting authority eliciting the statement of requirements R and
- the *solution space* M of the prime contractor prescribing the program P that implements the specification S .

This is recursive to the operational solution.

Another important distinction is that the machine has to guarantee a restricted operative form S of requirements R while the environment has to guarantee a complementary indicative form W of requirements R . The consideration of the human H in this framework introduces two new specifications, one UI which determines the Human-Machine interface and the other I which determines the knowledge K and behaviour that is expected of the human as a component of the socio-technical system.

Our work restricts the formal predicate $W \wedge S \wedge I \wedge UI \Rightarrow R$ of this reference framework to $W \wedge S \wedge UI \Rightarrow R$ in order to specify both the technical intelligence to be embedded into

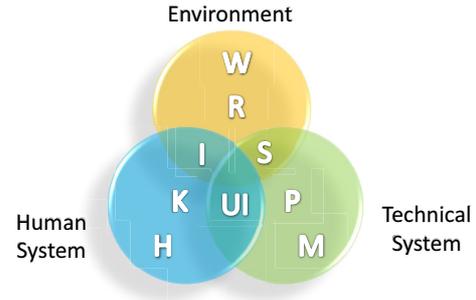


Fig. 2. Requirements analysis model for socio-technical systems (Hall and Rapanotti (2005))

the machine and the digital capabilities to be provided to the human for interacting with the machine (Fig. 3).

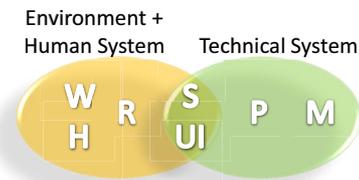


Fig. 3. Specifying the digitalization of the human to technical system interaction

Specified requirements are considered as specification S and are considered as the central structure of the system's requirements repository. Indeed, this requirement repository of our socio-technical system is built by successive refinements and derivations of the original requirements taking into account the domain knowledge. Thus, compared to the realized task, in each work domain a portion of the repository is kept, and allows to achieve traceability between specified requirements.

3. SPECIFICATION METAMODELING

Our Systems Engineering (SE) proposal is built on the pillars of SysML modelling language: the machine M is modelled using the *structure* pillar, the program P is modelled using the *behaviour* pillar and the requirements and specifications are built using the *requirement* pillar.

As the SysML standard does not consider methodological aspects, in order to guide the designer in considering all factors (W, R, S, P, M) in system modelling, we propose to support this modelling approach by extending SysML meta-model (Fig. 4). Some constraints are also defined like: "the SpecifiedRequirement must be satisfied by a Structure that has at least one Behaviour", and "the SpecifiedRequirement must be verified by one TestCase", etc., and expressed using OCL formal language.

As SysML is a semi-formal language, it can not be used to formally verify or validate specified requirements. Thus, in conjunction with SysML one must take into account the use of formal languages and tools for specification verification, and simulation languages to validate this specification.

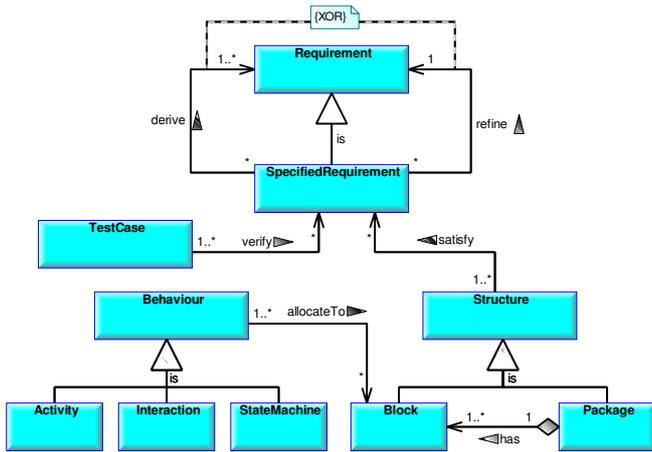


Fig. 4. SysML meta-model extension for specification integration

4. ENGINEERING THE HUMAN TO TECHNICAL SYSTEM DIGITAL INTERACTION

4.1 Interaction specification in industrial system control

Nuclear Power Plants (NPP) are complex systems with a large number of components. In order to achieve process functions, the main control operations request alignment of circuits (*R*). As explained in section 2, this supposes a large numbers of manual operations which are often cause of errors, due mainly to the lack of process knowledge. This context corresponds to the *problem space* (Fig. 5).

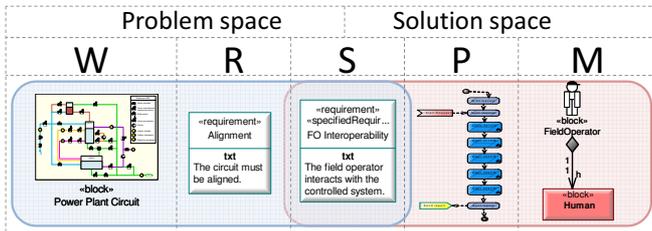


Fig. 5. Field operator's interoperability specification model

Alignments are executed by control-room operators on the instrumented components and by Field Operators (FO) on the non-instrumented ones. Regardless of their human nature, FO can be considered as components of the system (*M*). They apply predefined procedures as programs (*P*) in order to achieve the alignment objective. The FO with the procedures set corresponds to the *solution space* to our alignment objective (Fig. 5).

The specification corresponds to the intersection of both spaces. It specifies how the FO must execute the procedure on the power plant circuit in order to satisfy requirements. To execute the procedure, the FO interacts with the controlled system, but this interaction can be source of errors caused by human biddable nature. Our objective is to facilitate the interaction between the FO and the controlled system by digitalizing it.

4.2 Specifying the digitalization of the technical system

Furthermore, in order to solve the FO interoperability problem, the solution space of the field operator becomes

the problem space. Since the manual valve is considered as the object of interest in the FO interoperability issue, we propose to augment valve's capabilities by offering services like action authorization, verification, validation, etc. Since the system will be in relation with the FO, one of the main specifications of the enhanced valve is the interoperability with externals systems Fig. 6.

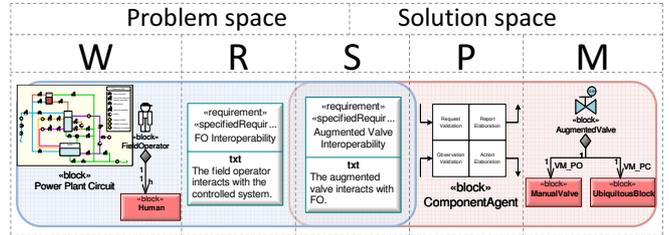


Fig. 6. Augmented valve specification model

The internal structure of the augmented valve is composed of two parts (Fig. 7): the manual valve and a ubiquitous module. The operations on the manual valve are executed by the FO using the *I_Motor* interface which requests operations like `setState(state:Bool)`. The manual valve exchanges with other physical components water flows. On the other hand, the ubiquitous module exchanges through its services with external systems information flows like requests of actions to be executed on the valve or reports about states and errors from the valve. This way, the ubiquitous module increases the valve's digital capabilities and integrates interfaces with the external world. The two parts exchange the opened/closed states.

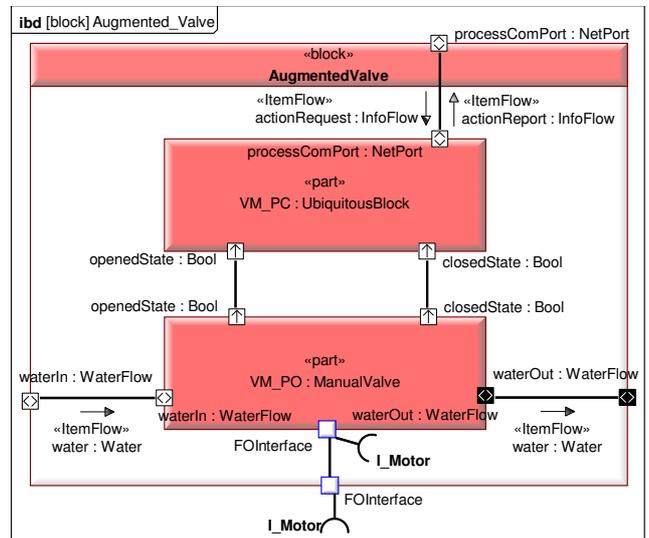


Fig. 7. Internal bloc diagram of the augmented valve structure

The behaviour of the augmented valve is refined from the manual valve's passive behaviour, activated by FO's actions. The added states correspond to the behaviour of the ubiquitous module integrated as an IAM module: states for action authorization, validation, and error reporting (Fig. 8).

As described in the proposed SysML extension (Fig. 4), a TestCase is done to verify the specified behaviour of the augmented valve (Fig. 9). Because of the nature

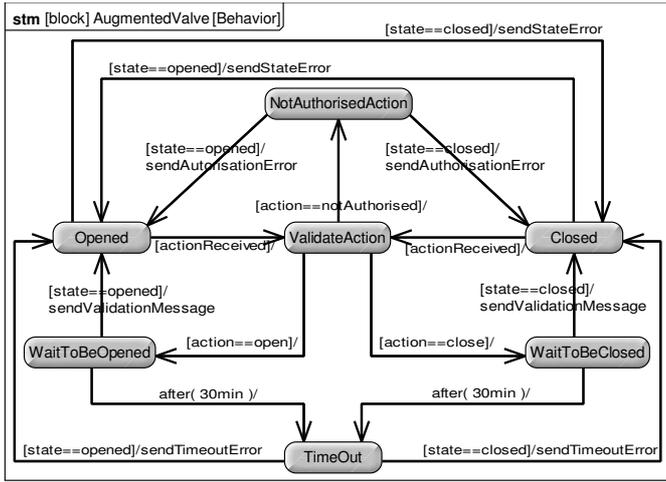


Fig. 8. State machine of the augmented valve behaviour difference between the field operator and the valve, they can not interoperate directly, so the action request must be provided from the valve's environment (i.e. the control system).

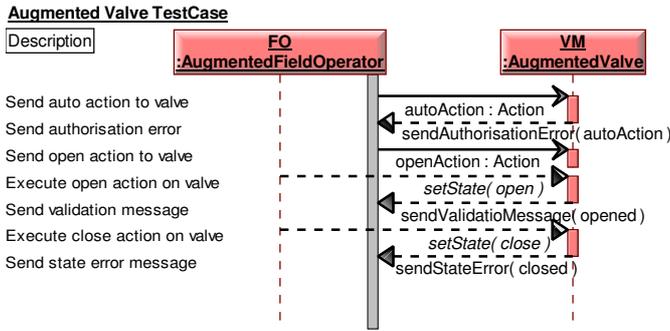


Fig. 9. Augmented valve Test Case

The augmented valve specification provides the desired behaviour on the interface between the valve and the environment. However, in order to provide numerical interoperability function for the FO, a digital interface must be specified for the FO.

4.3 Specifying the digitalization of the FO

In order to equip the FO with the ability to communicate with the augmented valves (to solve the nature difference problem), the solution space which is now considered extends the FO's capabilities with some computing abilities (Fig. 10), provided for example by a computer system.

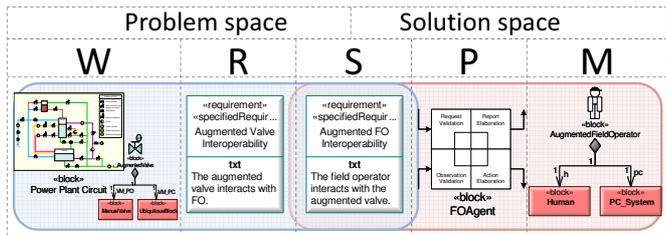


Fig. 10. Augmented FO specification model

The computer system must allow the numerical interaction of the FO with the augmented valves and with the CMMs.

So, two types of ports are specified, one for the fieldbus and one for the process. This allows the distinguish of the two flow types: the Operating Procedures (OP) flow and the ac-tions flow. From the fieldbus, the FO receives the operating procedures requests and sends reports. Using the process port, the FO sends action requests to the augmented valves and receives authorisations and reports about executed actions.

Considering the structure of the augmented FO, we must take into account the human operator interfaces (motor, vocal, tactile, visual, auditory, etc.) that he requires and provides, to specify the user interface of the computer system (Fig. 11). In order to visualize the requested procedure, the FO requests some graphical interface. Their communication with the con-trol room operator for procedure synchronization is made using some in/out audio interface. Moreover, observations and reports are introduced using some tactile interface. On the process level, manual actions are executed by the human operator using the motor interface and any abnormal behav-iour is detected by the visual interface.

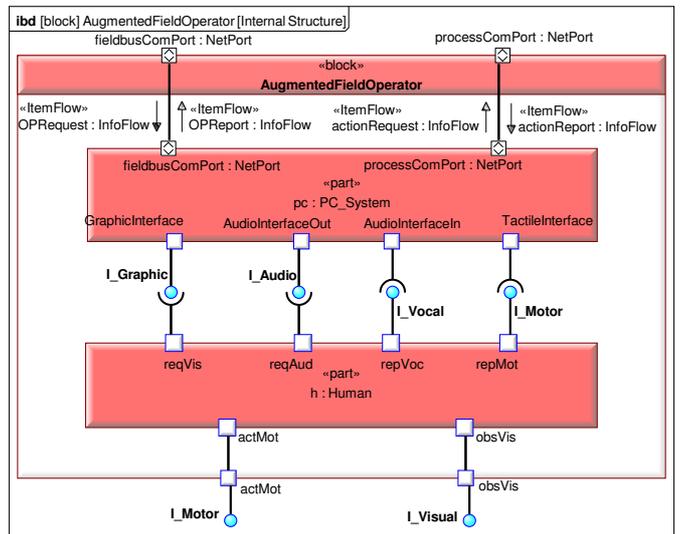


Fig. 11. Internal block diagram of the augmented field operator structure

In view of the elements of the augmented FO, its behaviour is composed of the computer behaviour, based on a software agent, and the human operator behaviour, which includes judgment capabilities based on experience and training, not implementable in a software agent (Fig. 12).

This behaviour can be verified by the Test Case described in Fig. 13. This time, the interoperability between the augmented FO and the valves allows direct interaction for action request and report.

4.4 Specification global view

Using the specification meta-model described in part 3, Fig. 14 summarizes the engineering path from the initial alignment requirement to the specified solution elements: interoperable augmented FO and valve.

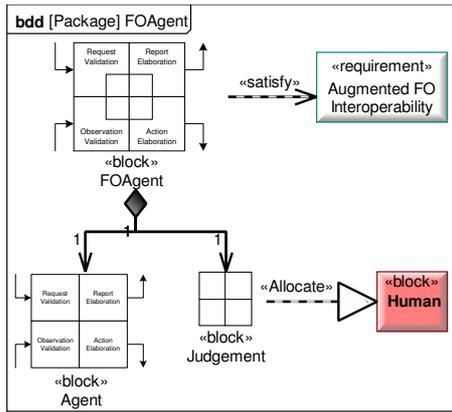


Fig. 12. Allocation of augmented FO judgment

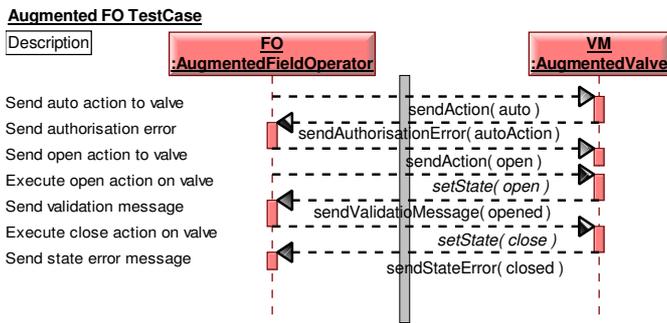


Fig. 13. The augmented FO test case

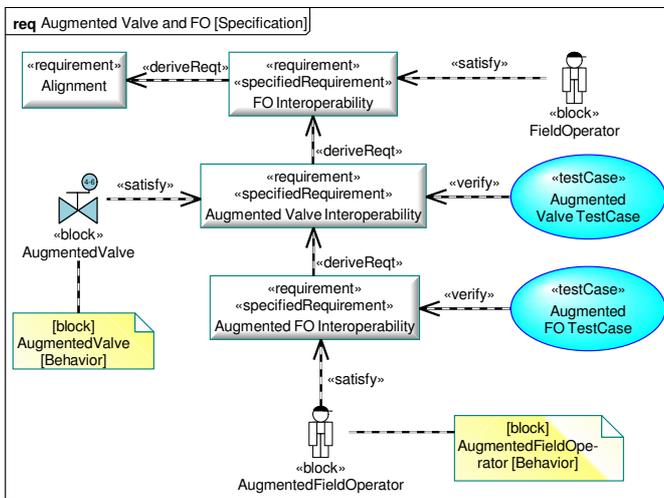


Fig. 14. Augmented valve and FO specification

5. PROTOTYPING THE DIGITAL INTERACTION

Infotronics technologies (RFID, wireless sensors, etc.) gives the opportunity to implement the CMMS / IAMS paradigm as well as the "ambient intelligence", to digitally enhance the human-system interactivity (Dionis and Pirus (2007); Iung et al. (2009)). This brings to conceptually encapsulate the channel of materials and energy through a channel of information. In order to normalize the digital interaction between physical, informational and human levels, human operators will access information via a service channel (Fig. 15).

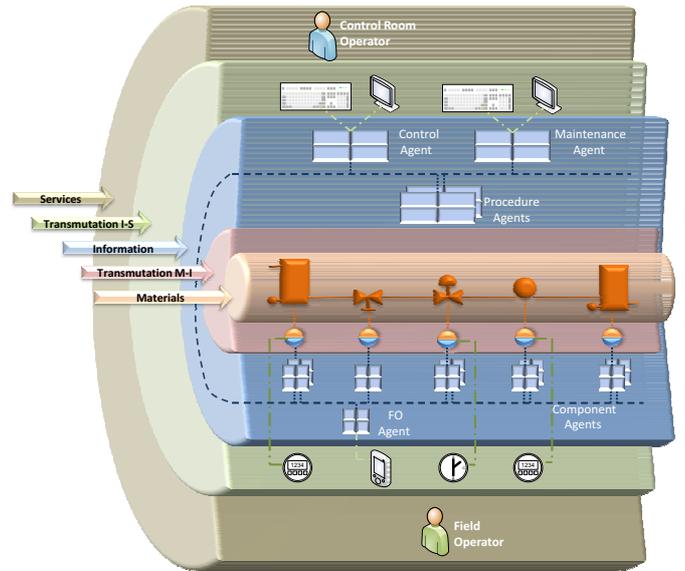


Fig. 15. Digitalizing the technical system

An industrial PDA with Windows Mobile 6 has been used as FO computer system.

The augmented valve specified solution has been prototyped using manual ball valves with end limit switches on which we have attached MicaZ wireless sensor module with the MDA300CA data acquisition board from Crossbow (Fig. 16). Using the digital inputs from the acquisition board we have manage to gather the valve's open/closed position state. These states are then used to validate the actions executed by the FO. The interaction with the FO's PDA is realised using the Netbridge Stargate gateway interface.

The action authorisation is realised by comparing the action to be done sent by the PDA with the allowed actions on the valve (for example, the manual valve allows only "OPEN" and "CLOSE" actions and not "AUTO" action allowed on a linear instrumented valve) and the current state of the valve ("OPEN" action can not be executed on a opened valve). Object-to-Object interactions are also tested in order to analyse action dependences rules based on valves state positions (for example, one valve must be opened before another valve or two valves can not be opened in the same time). This can be done from distance, even before to localise and identify the valve. Considering an operating procedure, the authorisations of actions can prevent the time lost in localisation of already in state valves.

RFID tags are also employed for the localization (identification) of valves in order to guarantee that the current action is executed on the right valve.

As soon as the action is executed, the module is capable to validate it by comparing to the action to be done. Of course, if an action is donned without having a validation before, an error is sent.

The implemented behaviour has been validated using the specified TestCases.

As only the feasibility of the specified solutions using a wireless technology is evaluated, problems related to

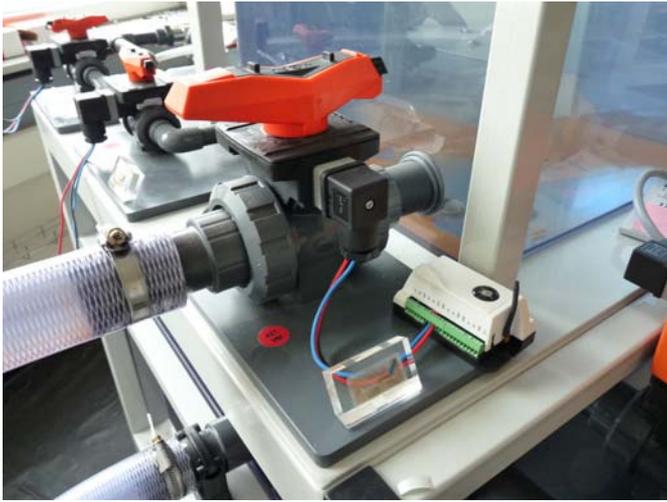


Fig. 16. Augmented valve with RFID tag and WSN module
the WSN domain like power consumption, radiofrequency band, communication protocol, etc., studied by the WSN community, have not been considered yet.

6. CONCLUSIONS AND PERSPECTIVES

To contribute to master the complexity of process operation, this paper studies the possibility to improve the interaction between the human operator and the technical system by digitalizing it. It proposes to augment manual valve and human field operator capabilities using ambient intelligence concepts and technologies.

From a systems engineering point of view, this paper presents a requirement analysis model for socio-technical systems which is used to specify the technical intelligence to be embedded into machine and digital capabilities to be provided to human. The specification is supported by an extension of SysML, and is done by recursive derivations and refinements of an initial problem space requirement via specified requirements of solution spaces, to the operational solution.

Perspectives of this work concern the formalisation of the specification concept and the implementation of the digitalized interfaces on a lab platform. Object-to-Object interactions are also studied in order to analyse action dependences rules based on valves state positions.

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