Education in Industrial Automation in an Innovative Learning Factory

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Abstract

Education courses on automation usually address the development of a control system considering only simplified theoretical frameworks and using nominal simulations in order to verify the correctness of the developed control solution. This approach contrasts with industrial practice where automation systems are usually developed on the basis of the engineers experience and directly tested on the real industrial plants, without any verification step among design and implementation phases, generating high commissioning times and costs. To bridge the gap between such approaches, a dedicated mechatronic laboratory integrated into an innovative RTDI factory has been set up by ITIA-CNR. Such infrastructure is strongly exploited for technology-enhanced learning of industrial engineers that may get confident at the same time with different automation methods and tools as for models, algorithms, simulations, devices, instruments and communication networks. Clear benefits have been experienced through the training of both students and industrial technical workers during master and life long learning activities.

Keywords:

Automation, Learning, Control-lab

1 INTRODUCTION

Education courses on automation usually address the development of a control system starting from the functional specifications, considering the mathematical modelling of the control algorithms and running simplified software simulations to verify the correctness of the designed control system. This approach contrasts with industrial practice in which the development and implementation phases of an automation system are poorly based on mathematical models and rely on the expertise and knowledge of the system engineers. Moreover the validation of the real size control solution is mainly carried out directly on the real industrial plant. The first approach is structured but is not feasible because of the complexity of real-size industrial applications. The second one is unstructured and thus can lead to critical problems in particular during the testing of the automation solutions in which commissioning time and costs are very important aspects. To bridge the gap between such approaches it is fundamental to support control system engineers by allowing the use of a structured design methodology so to conceive, study, design, implement and verify an industrial automation system, as described in chapter 2. To support such a structured development, a dedicated mechatronic laboratory integrated with an innovative Research, Technology Development and Innovation (RTDI) factory has been set up by ITIA-CNR whose structure is showed in chapter 3. This infrastructure is also strongly exploited for technology-enhanced learning of industrial engineers. In fact such technological platform is very useful, not only to test plant automation strategies, but in particular for engineers learning process because they can use such automation technology as a trainer, able to increment their know-how and technology expertise. Moreover engineering students have the possibility to increase their technical skills by applying the theoretical knowledge not only on virtual instrumentation but also on real devices. These concepts will be better explained in chapter 4.

2 THE ADOPTED STRUCTURED DESIGN METHODOLOGY

Reliable and agile automation systems are a crucial point for competitiveness of modern manufacturing systems [1]. Interoperability, portability and scalability of developed automation solutions are also fundamental elements to reduce the costs and times needed to design and realize a new production system, or to modify an existent one. In such a context, the definition of development methodologies that support the structured design and testing of the whole automation system of a manufacturing plant is mandatory [2]. One of the key elements of the proposed approach is the adoption of a structured design methodology [3]. This is based on formal reference models, considering object-oriented paradigm [4] and compliant with IEC international standards. A structured development methodology for the design of industrial automation systems is based on a Design Cycle Model (DCM) that establishes the order of the involved development phases.

1. *Industrial process and automation system definition.* The industrial process must be described in terms of the behaviour of the mechanical structure integrated with the regarding instrumentation so the functional requirements can be defined. The process specifications represent the basic requirements for the whole development of the control system [5]. In general, nowadays, such specifications are carried out by means of narrative descriptions without using any rigorous formalism. This approach doesn’t allow neither obtaining any useful element to be automatically used in the following design phases nor support documentation updating and consistency in case of plant revamping, in particular when industrial processes and controls systems have to be maintained or modified [6].

2. *Automation system architectural design.* Starting from the system definition, the tasks and the essential functions of the supervision and control system are defined by structuring them into a hierarchy of different layers (plant, area, cell, unit, control system devices) based upon

successive decomposition from top-level control objectives into elementary control actions. In the industrial context, in few cases the architectural design is formalized to complete the automation system documentation while often it is not carried out because control engineers jump directly from the automation system specification phase to control code implementation. Nevertheless, such an activity is very useful because it allows distributing and balancing the hardware resources and regarding software load on the different available devices, so to using in efficient and effective way the available automation technology.

3. *Automation system functional design*. Each control module defined in the architectural design is detailed according to its modular composition and control functionalities. Also this activity is often neglected from industries because it apparently seems not giving direct contributes to the software implementation. On the other side current practice shows that re-implementation of the control software code is often preferred to maintaining an old one because of the huge amount of time and cost requested just for lack of any control system functional approach. However whereas such design phase is carried on in general no standardized methods and tools are adopted so no automatic data generation can be performed and exploited during the software implementation phase.

4. *Automation system implementation.* The automation software is developed by using a specific software configuration platform and language. Such choice impacts on long term industrial plant management because the acquired knowledge from plant operators will be specific for a particular software environment. In case of automation system maintenance or revamping it will be mandatory using similar control system architecture and configuration environments to cope with the consolidated operator technical skills. Moreover this can obstruct the possibility to migrate toward further innovative and more powerful industrial automation system solutions. The adoption of innovative standardized formalisms instead allows re-using of both proven automation solutions and plant operator skills also in case of different automation systems, reducing in this way development time and costs.

5. *Control code verification and system integration.* Within such phase, the correspondence of the emulated automation system behaviour according to the requirements described in the system specifications is verified. A structured way of validating the control software consists of using process simulators which are not widely used from industries because their implementation requires deep process competencies and additional costs about modelling and programming activities. In fact in general, once the implementation phase is completed, the control software is downloaded onto the industrial hardware devices and tested in this way directly on the field by controlling the real industrial process. This apparent shorter way involves the increasing of commissioning time and costs needed to eliminate software programming errors besides possible dangerous actions that could be executed for plant devices.

3 THE MECHATRONIC LABORATORY DEVELOPED BY ITIA-CNR

3.1 Requirements

The main requirement that leads to the study, design and implementation of an automatic control laboratory integrated into an innovative RTDI factory comes from the needs to verify the control software of the real plant using closed-loop simulation techniques, in particular “hardware-in-the-loop” simulations by means of Discrete Events Systems mathematical models. In order to face in an effective way this step of a generic automation design process, the existence of a control technology infrastructure has been considered necessary, which should provide functionalities and technologies to carry out each of the different phases of the design methodology presented in section 2.

The different design methodology phases are based on specific engineering methods and technologies: for example while the control algorithm design step needs a software environment that allows the implementation, compilation and software emulation of the algorithms, the phase regarding the control software implementation on the target hardware needs hardware components to properly verify the results. These operating needs require a structured and articulated hardware and software environment.

In the specific context, the implementation of the “hardware-in-the-loop” simulations by means of Discrete Events Systems mathematical models can be supported by means of the following main technological areas.

- The control system algorithm emulator, running on the control devices.
- The process simulation model, running on suitable simulation tools.
- The small scale plant of the process to be controlled.

Such areas must be connected among them by means of a suitable electronics and cabling system in order to exchange input and output variables both for the control system and the process simulator. Moreover a communication system among the different hardware devices is necessary so as to create an integrated device network including the small scale plant component.

3.2 Overall architecture, functionalities and tools

In order to realize “hardware-in-the-loop” simulations it is necessary to develop a control system that emulates the automation control functionalities and that is interfaced to a process simulator that describes the physical behaviour of the real plant. So it’s possible to test the designed control algorithms before their implementation into the real plant target control system, reducing the plant commissioning time and then the associated costs. The tests are carried out by emulating the control system strategies in an opportune hardware and software platform.

In real plant the control system functions receive the information about the controlled process by means of measured process variables and they elaborate and sent back specific control actions, by means of input and output boards. In order to represent such process information at design phase, this can be simulated by means of proper process mathematical models. The main purpose of the process simulator is to verify the designed control system functions, so the process model evolves according the control actions determined by the control systems to be tested.

It must be highlighted that the mathematical models normally used in such a process simulator simplify the physical behaviour of the real plant, in particular nominal working function conditions are taken into account. In this way it is not possible to verify the control algorithms behaviour under instrumentation failure conditions. In order to overcome such a limit it is useful to exploit a small scale plant build by mechanical and electronic modules that reproduces the same real plant functional behaviour. Such a small scale mechatronic device provides real electronic signals, so it may suitably represent also unexpected behaviours deriving from possible failures that could happen on a real plant. The advantage with respect to the single process simulator is that operational aspects and non nominal working function conditions can be verified to a larger extent. Therefore a third technological area, i.e. a small scale plant, is present into the mechatronic laboratory architecture which is interconnected to the control system like the process simulator. In Figure 1 the general architecture of the mechatronic laboratory is sketched.

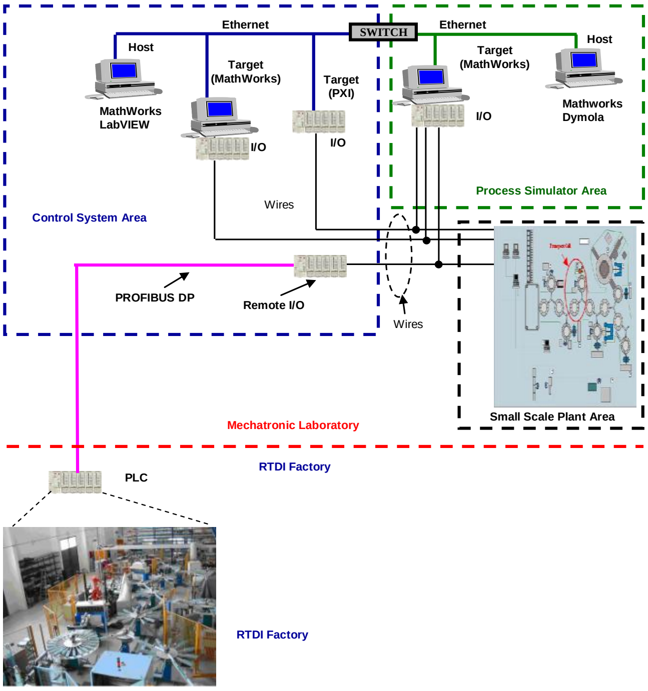

Figure 1: Mechatronic laboratory general architecture.

Control system area

The control system area is based on two different platforms that allow emulating both continuous and logical control functions. The environments are Matlab (by MathWorks) and LabView (by National Instruments). Both systems are characterized by a structure based on two PC: a HOST PC on which the control software is designed, configured and implemented and a TARGET PC (PXI device for National Instruments platform) that is used to run the designed control code in soft real-time mode. The TARGET PC has physical output boards to force the control actions and physical input boards to acquire the measured variables from the process. Both in case of process simulator or small scale plant connected to the control devices, the format and the meaning of the acquired process variables doesn’t change; in the first case they are simulated variables converted into electrical signals while in the second case they are just electrical signals coming from the small scale plant instrumentation.

Process simulator area

The process simulator area is based on only one platform with two different software tools that can be integrated. With these tools it is possible to model manufacturing plant by means of both discrete event systems and continuous processes. The two software tools used are Matlab (by MathWorks) and DYMOLA. The platform consists of a HOST PC on which the process models are implemented and a second TARGET PC where compiled process model software run in soft real-time mode. This second PC has physical input boards able to receive the control actions sent from the control system and physical output boards to send the simulated process variable. As said above, the simulated variables are converted into electrical signals to be exchanged between the two interfaced systems.

Small scale plant area

The small scale plant is based on mechanical devices provided by actuators and sensors. The connection of these actuators and sensors with the control system area is obtained by mean of physical input and output electronic boards placed inside the TARGET PC devices. Obviously the technological compatibility among actuators, sensors and input and output electronic boards is fundamental in order to make the interconnection among the devices of the different technological areas possible. In Figure 2 a picture of the small scale plant is showed.

Figure 2: Small scale plant.

Research, Technology Development and Innovation (RTDI) factory

The real plant is made of mechatronic devices, i.e. small mechanical machines and real control system hardware (PLCs). In order to effectively validate the control software of PLCs it is important to perform testing operations running directly on the PLC hardware so as to avoid possible control software language translation errors during software implementation phases. To do that, the PLC can be interfaced either to the process simulator or to the small scale plant into the mechatronic laboratory by means of a real time fieldbus connection. In this way the PLC is able to control the mathematical model of the process or the small scale plant without any functional and/or operational difference.

Cabling system

The control actions and process variables exchanges don’t present conceptual obstacles if standard electronic interfaces are implemented. In particular in case of interconnections between the control system area and the process simulator there are no problems because the electronic input and output boards have the same technology, so a direct connection can be executed. On the other hand, in case of connection between the control system area and the small scale plant, specific electronic interfaces must be implemented so as to interface the electronic input and output boards of the control system area with the different sensors and actuators of the small scale plant that are in general characterized by different electric characteristics (dry contacts, magnetic sensors, electronic relays, etc.). Similar electronic interfaces must be adopted to connect the RTDI PLC hardware with either the process simulator or the small scale plant.

4 ITIA-CNR LABORATORY EXPERIENCED BENEFITS

The exploitation of a structured design methodology for automation systems highlights a set of problems concerning the industrial practise about the design and implementation of control systems. The conceiving and realization of the presented modular structured technological mechatronic laboratory allows carrying out the implementation of the different phases of the structured development methodology, by increasing engineers and students automation skills.

Automation engineers

In particular automation engineers who have to face the problems highlighted from the structured methodology are able to practise themselves with new methods and technologies that usually they can’t use in the industry for different reasons, such as the short development times imposed by the clients. In this way the acquired skills on control system development and in particular the increased knowledge about innovative automation concepts represents a very high added value for the automation engineers.

Students

Students interested in automation disciplines have big advantages by using such a configured laboratory. In particular its modular architecture allows interconnecting the different technological areas without any interface obstacle. In fact they are able to increase their skills on different aspects. As for control algorithms it is possible to develope control strategies at both discrete event and continuous levels. About the mathematical simulation they can implements dynamic and discrete process models with different levels of accuracy. Moreover it is possible to get experience on the basic automation technology by means of a real small scale mechatronic device equipped with different type of sensors and actuators. But the most important added value for the education of students is giving them a wide and complete overview of an automation system environment and development process, starting from the emulation of the control system devices, through the verification of the implemented algorithms running onto the process simulator, and the testing on a physical application with the possibility to better understand the difference between nominal and theoretical conditions from real physical conditions, including sensors and actuators failure, to be considered for the robustness of the overall control system validation.

5 CONCLUSIONS

This paper presents the usefulness of a mechatronic laboratory as trainer for engineers and students education on industrial automation. In particular, starting from the needs of automation engineer designers, the ITIA-CNR mechatronic laboratory architecture is described in the paper as well as the experienced benefits for students and automation engineers that have been involved in education and life long learning activities on the presented infrastructure.

6 REFERENCES

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