DEVELOPMENT OF HYBRID LABORATORIES OF INDUSTRIAL SYSTEMS FOR INTERACTIVE LEARNING OF AUTOMATION AND CONTROL

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Abstract

This paper describes a new approach of laboratories for industrial systems, specifically, hybrid laboratories, which are a mix of real and virtual laboratories. The hybrid labs proposed have physical control devices in the real part, and simulated components and processes in the virtual part. Through the combination and connection between both parts, it can take advantage provided by both real and virtual laboratory. An architecture for interactive learning in Automation and Control has been developed through the Easy Java/JavaScript Simulations (EjsS) tool, Modbus communication protocol and a Programming Logic Controller (PLC). The virtual model is simulated by EjsS, the communication and handling of variables is done through the Modbus protocol to exchange the values of the inputs and outputs between the virtual plant and the PLC. To illustrate this architecture, two case studies are presented: the automation of a robotic cell and the control of a tank level. Laboratory practices have been developed following for several courses following some learning objectives.

Keywords: Automation and Control; Interactive Learning; Hybrid laboratories; Virtual and Remote laboratories.

1 INTRODUCTION

Industrial machines have had a high technological evolution in recent years. Currently, the industry requires professionals with knowledge in this field who can take advantage of the benefits of these industrial machines. In engineering education, this knowledge needs to be put into practice by means of practical laboratories.

The new technologies have allowed to create online laboratories, differentiated of two types, virtual and remote laboratories. In the virtual labs are used virtual-simulated devices, and in the remote ones, are employed real devices. Currently, technology is allowing to put together both types of laboratories, which have many similarities. The advantage of virtual laboratory machines is that they do not require physical space, the cost is lower, and they are easily scalable. As for the remote laboratories, students can interact with real devices, analyse real results and delays, with all the complexity that comes with a real machine [1].

The hybrid laboratory allows students to learn from the design phase, using the learned theory, to the experimentation phase with real devices. The hybrid laboratory is a combination of a virtual laboratory and remote laboratory devices. They include laboratories with real experimentation and simulation environments. These online hybrid laboratories provide real experiments transferred to the virtual laboratory, as well as simulated experiments transferred to the real laboratory [2]. Therefore, in a hybrid laboratory, the student can combine physical and real resources with virtual simulations, taking advantage of one another. In Figure 1, it can be seen where the hybrid laboratories are included.

The remainder of this paper is organized as follows. Section 2 explains the system architecture of hybrid laboratories, that is, the hardware and software necessary to implement them in the framework of industrial automation and control. Section 3 proposes some case studies of hybrid laboratories about industrial processes. The teaching framework is exposed in Section 4, which refers to the courses and main learning objectives. Finally, some conclusions are shown.
2 SYSTEM ARCHITECTURE OF THE HYBRID LABORATORIES

The hardware and software architecture proposed for these hybrid laboratories is based on the Modbus communication protocol, Schneider Modicon M340 PLCs, and EjsS. This architecture allows to develop hybrid laboratories in the framework of industrial automation and control. Specifically, the designed hybrid laboratories refer to the interconnection of a real PLC (real part of the hybrid laboratory) and a simulated industrial plant (virtual part of the hybrid laboratory). The virtual simulation can provide data from virtual sensors to the PLC and modify the behavior of the virtual plant as a function of the PLC’s program. This approach consists of real and virtual elements which cooperate to achieve desired educational goals. The interaction between real equipment and virtual processes provides a realistic scenario, allowing a deep understanding of the problem.

Hardware layer is composed by the real equipment, which includes the controller PLC, a switch device for Ethernet communication and the PC where the virtual plant is executed (Figure 2). In the case of software layer (Figure 3), this is composed by the software Unity Pro in order to program the PLC, the communication Protocol Modbus and the virtual plant developed with EjsS. This free software platform allows the modelling and representation of industrial processes with a realistic graphical interface and an accurate model of the plant (physical model) improving usual SCADAs development tools. As it is shown in Figure 4, the sensors of the virtual plant are connected by means of Modbus Protocol with the input and output memory of the real PLC.

2.1 Virtual plant modelled with EjsS

Easy Java/ Javascript Simulations (EjsS), is a free authoring tool written in Java that helps non-programmers create interactive simulations in Java or Javascript, mainly for learning purposes [3]. EjsS allows to implement the model of virtual simulations thanks to its physical engine based on differential equations. In addition, a complete library of graphical elements can be added to an interactive environment in an easy-way. This software has been selected by its flexibility to design the graphical interface and because of it has several programming elements to perform industrial communications with real hardware devices. In the proposed architecture, EjsS constitutes the virtual part of the hybrid lab, where the physical model of the industrial process is simulated and sensorized.
2.2 Communication and management of variables

The development of this type of hybrid labs involves the communication among hardware devices and software elements. Therefore, the virtual model of the plant must be sensorized with a set of shared variables in order to monitorize it (these are the inputs and outputs of the system). In this approach, EjsS is in charge of both aspects, the management of these variables and the simulation of the dynamics of the continuous/discrete processes which are modelled in the virtual plant. Moreover, the management of variables consists of updating the state of the virtual plant as a function of the data provided by the control program implemented in the PLC. These shared variables are updated with Modbus protocol using Ethernet, which has been implemented and configured in the virtual plant through an EjsS element. This element communicates itself with the PLC for both sending the input signals of the virtual plant to the PLC and reading the output of the PLC program in order to update the virtual interface of the industrial process.

2.3 Process control of the virtual plant

The PLC device works as the controller of the virtual plant by means its program implemented. The control actions are executed as a function of the state of the model of the virtual industrial plant. This state is provided by means of the communication module. To do that, the state variables of the sensors which represent the virtual process input at each sample time have been mapped in the PLC memory (Figure 4). The output values of these variables are updated at each sample time by the communication protocol Modbus, to share them with the variables of the virtual process. Finally, these variables will update the interface of the virtual plant.

Figure 3. Software architecture of the hybrid lab

Figure 4. Inputs and outputs of the hybrid lab
3 RESULTS: AUTOMATIZATION OF A ROBOTIC CELL AND CONTROL OF A TANK LEVEL

In this section, two cases of study are shown: one about the automation of a robotic cell and another one about the PID control of a tank level. The first example can be considered as a discrete process, where inputs and outputs of the system are digital. The second example can be addressed as continuous system because there are some analog signals.

In the first case of study, the virtual industrial process simulates the process of a robot arm and a conveyor belt which transports objects (Figure 5). This 3D virtual plant has been performed using the RoboticsLabs library of EjsS software [4]. In this virtual industrial process, there are a robotic arm, a conveyor belt, and a box where the objects will be stored. As inputs of this discrete system are the Start and Stop of the process (Play/Stop buttons), a detection sensor at the end of the belt and another detection sensor in the box. The outputs are referred to the activation of the conveyor motor and the robot trajectories. Figure 5 shows some snapshots of the virtual plant working. Students program the PLC in an appropriate way in order to control the proposed system. To do that, the software Unity Pro tool must be used. This software allows the students transfer the developed program to the PLC, which can be implemented in different programming languages. Finally, students execute their program using the virtual industrial plant and to check their correctness by means the virtual laboratory interface.

The second case of study is about the PI control of a tank level. In this case, as inputs of this industrial are the Start/Stop, and the reference of the desired level (analog input). The control of the tank level will be performed using a PI controller programmed in the PLC. As output, the PLC sends the percentage of valve opening. Hence, students must implement the PI control and visualize the result of applying different constant values (Figure 6).
The hybrid labs are being used in the following courses with contents about industrial processes automation and control from University of Alicante: Automation and Robotics in the Computer Science Engineering degree, and Control Systems in the Automatics and Robotics Master’s degree. In both of them, there are some didactic units about automation and control, where the main learning objectives are: to explain sensors and actuators employed in the industrial systems; to explain the PLC device and its operation principles; to teach how to use the PLC to control industrial processes; to explain how to program the PLC based on IEC1131-3 norm; to explain basic concepts about classic control theory such PID controllers. As a part of the educational methodology, the hybrid labs are used as practical lessons of these courses. Students program the virtual plants as real industrial systems using the PLCs.

In order to achieve the commented objectives, four practical exercises are assigned to each workgroup (composed by two/three students). These practical experiments are adapted to its implementation with the PLCs available in the laboratory. Each workgroup must perform the following activities: 1) to analyze the industrial system and to identify all the variables (inputs and outputs); 2) to perform a diagram of events of the system functionality to obtain a model of the process; 3) to specify the table of inputs and outputs; 4) to develop the PLC’s program to control the process using the languages of the IEC-1131 norm.

This work proposes an architecture for hybrid labs based on real PLCs and the simulation of industrial plants. These kinds of laboratories are very useful for automation and control subjects since they allow modifying the behaviour of the virtual industrial plant by means of the programming of the PLC without the use of a real plant. This approach provides students automation and control learning of industrial virtual plants within engineering educational methodology.

**REFERENCES**


