VIRTUAL LAB FOR ONLINE LEARNING IN INDUSTRIAL AUTOMATION. A COMPARISON STUDY

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Abstract

In this paper, we present the development process of a Virtual Laboratory (VL) which consists of an industrial automation system emulating a physical mock-up available in the laboratory in order to enable online students to perform the same practical training than face-to-face students in Industrial Automation subject for Engineering on Electronics and Automation (GIEA). The developed VL has been evaluated in terms of not only the industrial automation system creation but also the programming of the Programmable Logic Controller (PLC) based on Ladder Diagram (LD) programming language and Human Machine Interface.

The developed VL allows online students programming the control of an industrial automation system in LD using a PLC including emergency stop and reset, manual and automatic modes and system feedback by means of HMI.

This study has been performed at the Escuela Universitaria Politécnica de Teruel, University of Zaragoza, which plans to gradually introduce the blended learning modality in all the courses offered to GIEA undergraduate students.

Keywords: Virtual Laboratories, online learning, Industrial Automation.

1 INTRODUCTION

Over the last two decades there have been fundamental changes in the teaching-learning process where Information and Communications Technologies (ICT) have played a key role. ICTs provide some solutions that could not be imagined some years ago as online and distance learning. Massive Online Open Courses having enrolled about 58 million people [1] as well as the effort of several institutions for attracting international students offering online courses [2] are clear examples.

In this way, the Escuela Universitaria Politécnica de Teruel (EUPT), University of Zaragoza is planning to offer blended-learning courses for undergraduate students of Engineering on Electronics and Automation (GIEA). Blended learning combines both online resources and traditional face-to-face activities. In a previous study [3] 13 core courses of the GIEA Engineering studies, including Industrial Automation, where analyzed evaluating the main available tools for practical training.

However, teaching online courses have difficulties. The teachers' workload to prepare them is high [4], [5], and usually require well trained workers and platforms for assisting teachers to create video-based contents [6]. Besides, it has been observed that students are less participative in the proposed online activities [7] and, in fact, only around 12.6 percent of MOOC students complete the courses [1]. In addition, traditional courses tend to get best students’ ratings that their online counterparts [8], [9]. For these reasons, there are several works studying different strategies to increase the interest and commitment of online students [4], [10], e.g., by using active learning methodologies [1].

Within the preliminary study for offering blended-learning in GIEA [3], a major concern relates to the way in which practical training will be offered to students so that they acquire the required practical skills. This is a common topic of discussion in Science, Technology, Engineering and Mathematics (STEM) undergraduate studies, due the high load of practical training [11], [12]. Several alternatives to traditional physical laboratories, which are better suited for online learning, have been proposed. Virtual Laboratories (VL) are the most popular alternative to traditional laboratories. In VL, students interact with simulated versions of physical laboratories that include virtual representations of equipment, machines, and materials through a computer. Although students of STEM seem to be attracted by VLS [13], virtual and traditional laboratories are often topic of discussion and comparison. Physical equipment is important so that students can develop practical laboratory skills, hands-on experience and troubleshooting of machinery [11]. Also, VLS must be carefully selected, since several
VLs give an oversimplified view of the scenario or provide ideal conditions [14]. On the other hand, VLs can improve the understanding of salient information by reducing confusing details. Besides, they are safer, cheaper, and allow changing the time scale or observing unobservable phenomena [11]. Several comparison studies report no differences between physical and virtual laboratories [11], whereas other works show that virtual and physical labs improve the acquisition of different skills, all of them of high importance for Engineers [12].

Specifically, Industrial Automation is a subject with strong applied content and the practices are divided covering fundamental functions of any industrial automation system (start and stop modes, communications, Human Machine Interface), so a major concern associated to blended-learning in this subject relates to the way in which practical training is offered to students so that they acquire the required practical skills. In the previous study [3], it was concluded that a high percent (66%) of the laboratory activities can be performed using Virtual Labs (VL) with the EasyPLC and Machine Simulator program.

In this paper, we present the development process of a VL which consists of an industrial automation system emulating a physical mock-up available in the laboratory for current face-to-face students. The VL is evaluated in terms of not only the industrial automation system creation but also the programming of the Programmable Logic Controller (PLC). Note that the main task for students is programming the PLC.

This paper is organized as follows. Section 2 makes a comparison of each element of the physical mock-up with the VL environment, then PLC programming characteristics of real PLC and virtual PLC are compared and finally Human Machine Interface (HMI) are also considered. Section 3 presents the VL environment developed as the main result, including the simulated automatic system, the virtual PLC programming and HMI. Finally, section 4 states the conclusions and future works are proposed.

### 2 METHODOLOGY

#### 2.1 Industrial system description

The physical mock-up of the industrial automation system is an Indexed Line with two Machining Stations [15] including a conveyor line, arranged in U-shape, for intermittent transport and for the machining of several workpieces. It is composed by a milling and drilling station, 4 conveyor belts, 8 DC motors, 4 limit switches and 5 light barriers, which implies the control of 9 inputs and 10 outputs. Figure 1 shows the industrial automation system.
2.2 Industrial system design

The simulated automation system has been designed using the “Machines Editor” software [16]. For each physical element, its virtual counterpart has been selected and configured. In addition, all the corresponding variables needed for each element control have been defined in order to be available for programming with EasyPLC.

2.2.1 Conveyor belt

A belt conveyor system is one of many types of conveyor systems. A belt conveyor system consists of two or more pulleys, with an endless loop of carrying medium—the conveyor belt—that rotates about them. One or both of the pulleys are powered, moving the belt and the material on the belt forward. The conveyor belts are simulated by the element ‘Conveyor’ which is composed by 1 output.

![Figure 2. Real and simulated conveyor belt.](image)

2.2.2 Light barrier

A photoelectric sensor is an equipment used to discover the absence or presence of an object by using a light transmitter and a photoelectric receiver. They are largely used in industrial manufacturing.

The light barriers are simulated by the element ‘Photocell’ which is composed by 1 input.

![Figure 3. Real and simulated light barrier.](image)
2.2.3 **Milling and Drilling stations**

The milling stations simulate the process of using rotary cutters to remove material from a workpiece by advancing (or feeding) the cutter into the workpiece at a certain direction while the drilling station simulates a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool.

The milling and drilling stations are simulated by the elements ‘MillStation’ and ‘DrillStation’ respectively which are composed by 2 inputs and 2 outputs each of them.

*Figure 4. Real and simulated milling and drilling stations.*
2.2.4 Pusher sorter

The conveyor pusher sorter pushes the pieces for changing it from a conveyor belt to the following one in the corners of the U-shape transportation system. The real pusher sorter system is composed of a DC motor and two limit switches indicating the barrier is in the extreme positions.

The pusher sorters are simulated by the element ‘PneumaticPusher’ which consists of a pneumatic cylinder and two limit switches and is composed by 2 inputs and 2 outputs. The element ‘ConveyorSimple’ has been modified by suppressing a lateral wall.

![Real and simulated pusher sorters.](image)

2.3 PLC programming

The model TSX-Micro Schneider are the PLCs available in the laboratory of the EUPT. This PLC allows three different programming codes based on the open international standard IEC 61131 for programmable logic controllers including Ladder diagram (LD), graphical, Structured text (ST), textual, and Sequential function chart (SFC), which has elements to organize programs for sequential and parallel control processing.

![PLC TSX-Micro.](image)
Ladder diagram represents a program by a graphical diagram based on the circuit diagrams of relay logic hardware. Ladder logic is used to develop software for programmable logic controllers (PLCs) used in industrial control applications. The name is based on the observation that programs in this language resemble ladders, with two vertical rails and a series of horizontal rungs between them. In this work, the industrial automation system is controlled by a LD program running in the PLC.

The PLC is simulated in the computer by means of the software “Easy PLC” [17]. This software also allows programming in LD, a ST and SFC. The same programming elements (rung input or rung output) are available in addition to timers and counters, so basically the same program developed in real PLC was programmed in virtual PLC.

2.4 Human Machine Interface

The HMI in the industrial design field of human–computer interaction is the space where interactions between humans and machines occur. The goal of this interaction is to allow effective operation and control of the machine from the human end, whilst the machine simultaneously feeds back information that aids the operators' decision-making process.

The Telemecanique XBTF024610 is the HMI available in EUPT laboratories. This HMI is 10.4" TFT operator terminals manufactured by Schneider Electric. This robust industrial terminal was sold under the Modicon brand in the United States. The XBTF024610 featured 12 static function key, 10 soft function keys, 12 service keys, RJ45 Ethernet 10TCP/IP connector.

The HMI interface allows the control of the automatic system by the operator. Emergency stop and reset, selection between manual and automatic modes, manual control of every actuator in the system in addition to the system feedback showing the state of the automatic system are among the functionalities developed by face-to-face students in the laboratory.

The HMI has been developed by means of the corresponding utility in EasyPLC Editor, which includes standard controls, graphical controls and external controls.

3 RESULTS

3.1 Industrial system design

Figure 8 shows the result of the simulated automation system. Each physical element has been simulated with its corresponding counterpart and all of them have been connected in order to define the Indexed Line with two Machining Stations.
3.2 PLC programming

The general operation mode of the system which has to be developed for face-to-face students has been implemented in “Easy PLC” by means of LD, and verified using “Machines Simulator” [18] by connecting the virtual PLC with the simulated automation system. This general operation mode includes manual and automatic modes, emergency mode and starts and stops modes.

There was a problem concerning the rising/falling edge elements in EasyPLC which was solved by Nirtec Customer Service after contact them. In addition, there is a difference when programming rising/falling edges since EasyPLC software considers these elements as rung output and the programming software for Schneider’s PLCs considers them as rung input. However this difference was easily solved by using an auxiliary variable.

3.3 Human Machine Interface

Figure 9 shows the main interfaces for the HMI, including the main menu, manual mode screen and automatic mode screen. There is a slight limitation for EasyPLC HMI System as images are static and modifying them based on system variables is not allowed.

Figure 9. HMI. a) main menu; b) automatic mode screen; c) manual mode screen.
4 CONCLUSIONS

In this work, the development and validation of a simulated industrial automatic system has been presented. This system emulates a physical mock-up in order to online students perform the same practical training than face-to-face students in Industrial Automation subject. The developed VL has been evaluated in terms of not only the industrial automation system creation but also the programming of the PLC based on LD programming language and HMI. The VL has been developed using the nirtect software including “Machines Editor”, “Machines Simulator” and “EasyPLC”.

The main conclusion is that the developed VL allows online students do the same practical training than face-to-face students. That is, programming the control of an industrial automation system in LD using a PLC including emergency stop and reset, manual and automatic modes and system feedback by means of HMI.

This study refers to students in Industrial Automation of GIEA at the University of Zaragoza. GIEA is taught at two centers, the EUPT and the Escuela de Ingeniería y Arquitectura (EINA). The EUPT plans to offer blended-learning courses but our results can be also of interest to face-to-face students in both EINA and EUPT centers to provide an additional tool that these students can use to reinforce their knowledge.

As future work, we plan to test the VL with students, in order to know their acceptance of the proposed solution, analyse ST and SFC programming languages with “Easy PLC” as well as PLC communication functionalities. Finally, the integration of the new VL with software tool that allows authenticated students to get at their own devices (PC, Mac, iOS, Android) a virtual desktop similar to ones available physically in our laboratories as “FlexVDI” [19] will be considered.

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