

Emulation of Real Processes to Improve Training in Automation*

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In the automation field, the coursework assignments are basically automation tasks that follow real systems. The reason why students need to work under this practical approach is because there is a constant need for industry-focused qualifications for new entrants to the job market. A practical orientation towards industry needs is required. However, many universities cannot afford the appropriate laboratory equipment to develop the required practical skills. A possible solution is to use computer emulations to support hands-on education and training. At the ITESM Tele-Engineering laboratory, emulated models have been developed and used for the last three years.

Keywords: automation; computer simulation; laboratory education; plc programming

INTRODUCTION

WITH THE MAIN OBJECTIVES of complementing the process rather than eliminating the real experience from the student and making it more efficient, the Electrical and Computing Engineering Department at ITESM Campus Monterrey has been developing and using, for the last three years, computer emulations of real industrial processes at the Tele-Engineering Lab. Results have shown that the students perform much better than in a traditional laboratory session.

An emulation is a computer model that mimics the operation of a real or proposed system. With emulations, different solutions can be implemented and tested without the availability of the real system. Emulations are goal-directed experimentation using dynamic models. Hence, they provide repeatable experimentation opportunities under controlled and extreme conditions [1–3]; students are able to experience several possible problems before facing them in real systems. As is expected and even desired, students make mistakes while programming. A serious mistake on a computer screen is infinitely preferable to a mistake in a real system.

Another important aspect to consider is that every student has his/her own learning method and also rhythm. We cannot expect to get the same results, in the same manner, from two different students [4, 5]. It is important to keep in mind that there may be several solutions for the same assignment and that the complexity between different solutions may vary. When students are restricted to obtaining a solution in a certain period of time within a laboratory session, their chances of reaching a correct solution could be

limited. By handing the emulations to the students, the laboratory concept is extended. They are then able to program, test and debug their PLC programs without being restricted to a scheduled laboratory session. The laboratory is, therefore, virtually always available.

MAIN ADVANTAGES

The aims of emulations are to gain insight, performance prediction and finding the appropriate input values for a desired behavior [3].

Therefore, emulations are useful to support education and provide training in areas where dynamic systems are involved [1, 2, 5, 6]. In the industrial automation field, there are several advantages in having an emulated system:

- **Costs:** one of the most noticeable benefits is the cost. Many universities cannot afford enough appropriate equipment, such as scaled models of industrial processes that help them to develop practical skills on the students. With emulations, universities could acquire a single model to equip their laboratories or even, if their budget is not enough, make the students practice with emulations only.
- **Debugging:** programming errors discovered using emulations would not be as costly, because errors discovered during the testing process would not damage the equipment. The use of emulations to debug the student's program considerably reduces the risk of errors in the real system.
- **Availability:** in most cases, only one system would be available and students would only be able to test programs on the system one at a time, making the process inefficient. This is not the case with the emulation, where students can

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test programs simultaneously, because each student could have a virtual duplicate of the system at his/her own computer.

- Animation: using animation to visualize system behavior greatly increases ability to spot problems and enhance students' learning [2, 7]. The process behaves accordingly to the student written code.
- Diversity: with diverse processes, the students can practice different programming techniques, enriching their qualifications. A University could have a library of emulated models, containing processes with different complexities, each of them to be used in homeworks, projects or tests.
- Versatility: with emulations you can quickly try out your ideas. Any promising solution is either accepted or dismissed much faster.
- Overall understanding: students have a better overall understanding of a new system or process when they work with its emulation. Sometimes sensors in real systems are not accessible or visible to the student. In the emulation, the location of each sensor is clearly specified.
- Handling of time: an often named advantage of emulations is that they (virtually) instantly show the results of a student's decision. Furthermore, the 'expansion of time' is also a major characteristic of emulators; users have more time than in reality to contemplate a complex situation and to make a decision. Emulators with adjustable time frames can be used [4].

PROCESS EMULATIONS: CHARACTERISTICS

Although we know that emulations do not always provide a perfect match for physical system behavior, they do attempt to duplicate a real system.

There are certain process characteristics that, because of their rare or occasional existence (such as hardware failures, external disturbances or even a behavioral modification), cannot be exactly replicated.

Therefore, emulations should be as similar as possible to the actual process. The operational characteristics of the sensors and the actuators must be preserved, such as the signals provided by the sensors and the required signals to activate the actuators. Also, it is desired that every sensor can be manipulated with a mouse click. This allows the user to activate the sensors at any time, the same way as in the real system using an external object.

Through a process of abstraction, we select those details that are most critical to characterize the operation of the system. The degree of detail required in a model depends on the nature of the system itself.

An important consideration when developing

emulations is the appropriate selection of the view to be used in order to have a complete visualization of the process. It is desirable that any possible programming error can be detected. Also, even when it is almost impossible to predict all the probable errors that could appear while programming, the behavior of the emulation before common error situations can be established. For instance, if an actuator used to move an object is not deactivated when the object has reached its physical limit, in the real system the actuator will be forced and the object will not move beyond this limit; in the emulation the object will continue moving off the screen, helping the student to detect the error.

Real processes: scale models

At the Tele-Engineering Lab several scale models of industrial processes are currently being used, such as: Transport and Sorting Lines, Process Lines with Machine Tools and 3-Axis Portals, from the Staudinger GmbH company.

The transport and sorting line model, shown in Figure 1, simulates a handling device to allocate part loads from a store register to various discharge stations, as used, for example, in a parcel distributor's logistics.

The transport and sorting line consists of a storage register with an integrated conveyor chain, a conveyor belt, three pushers and four discharge stations.

The scale model shows parcels being withdrawn from the store register, being recognized at an identification unit, getting transported to the corresponding discharge station by a conveyor belt and finally being transferred from the conveyor belt to the discharge station by a pusher.

Emulated processes

Each of the real models used at the Lab has been already emulated. These emulations were created using LabVIEW from National Instrument as the development tool, since it offers a graphical interface to the user, who can easily operate it.

The emulated model of the transport and sorting line is shown in Figure 2. As can be seen, a top view was selected to emulate this system. The reason is that this view provides a complete visualization of the process. Also, the location of each sensor is clearly identified.

The scale model of a process line with machine tool and its corresponding emulation are shown in

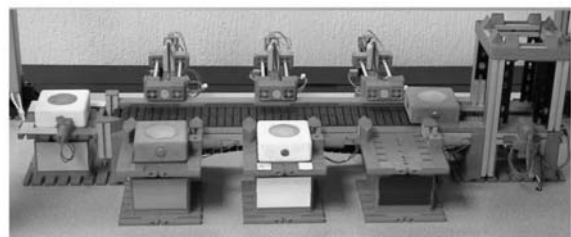


Fig. 1. Transport and sorting line model.

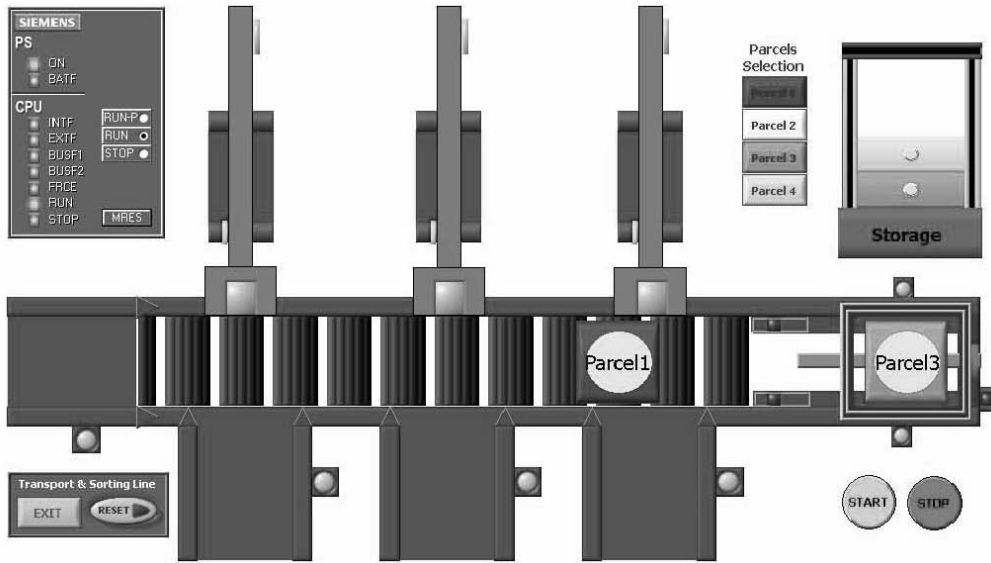


Fig. 2. Emulated transport and sorting line model.

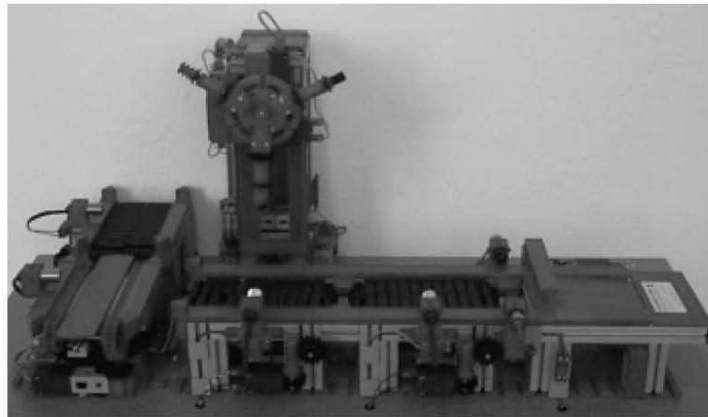


Fig. 3. Scale model process line with machine tool.

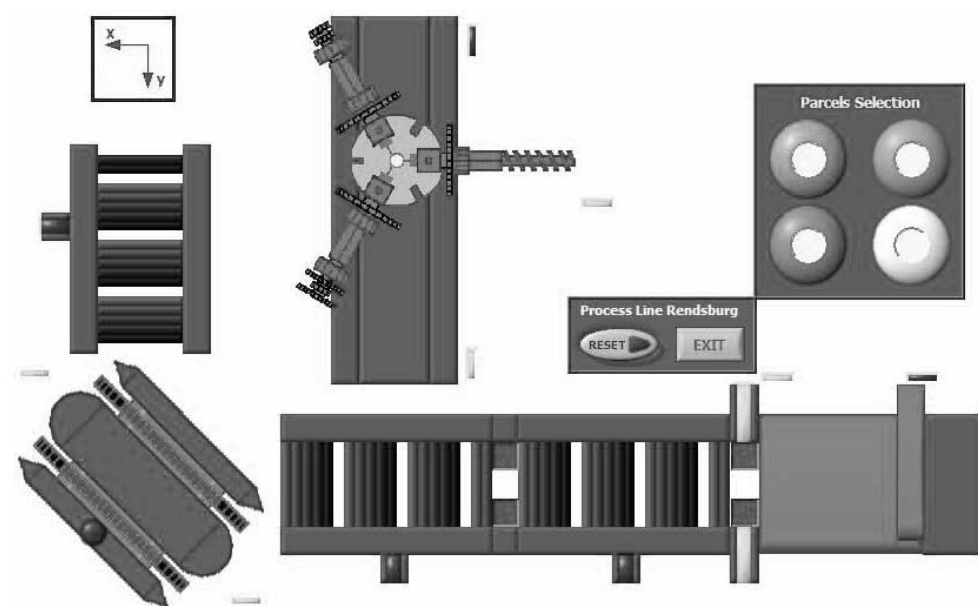


Fig. 4. Emulated process line with machine tool model.

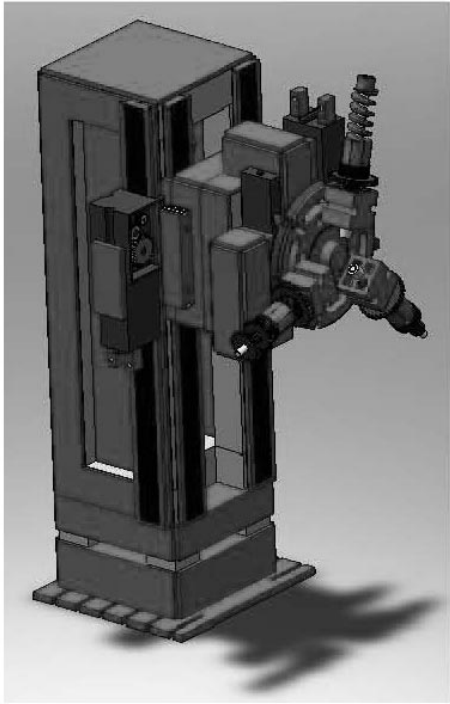


Fig. 5. Machine tool emulated on a 3D environment.

Figures 3 and 4, respectively. The process line consists of a turret drilling machine, three conveyor belts, a slewing table with conveyor chains and an automated lay-in-unit.

The scale model shows a workpiece being provided at the lay-in unit, then being brought onto the conveyance by a pusher, getting transported to the process cell, getting machined in several steps and finally being brought out to a discharge station by using the slewing table.

At the moment, a diverse library of third-dimension (3D) emulations is being developed. They offer, as could be expected, more characteristics than those in two dimensions (2D). In a 3D visualization it is possible to get immersed in the process and actually adapt the view to observe specific tasks or circumstances. A student can zoom, rotate or scroll the process at will (see Figure 5).

Taking advantage of the 3D visualization, students can observe the process from perspectives that most of the time are not available on real systems.

USE OF EMULATIONS

Before the development of emulations, students had to solve exercises and automation projects at the laboratory, only during laboratory sessions. This meant that often students could not finish exercises on time, since the automation tasks normally require a considerable number of tests to achieve a correct solution. If students wanted to prepare exercises before the laboratory sessions,

they could only sketch on paper a possible solution and were not able to validate it. Most often, a proposed solution contained programming errors that needed to be debugged and several tests were required.

This meant that either the exercises had to be designed in such way that they could be solved in a laboratory session, reducing their complexity, or that the same exercise had to be solved using different sessions. In both cases, the process was inefficient and the desired abilities were not developed in the students.

This is not so when using emulations. Students do not have to wait until the next laboratory session in order to validate their solution. Therefore, they have more flexibility to test and debug their PLC programs, because they can work wherever they want and without being restricted to a schedule.

For this purpose, students receive the tools required to solve different assignments outside a laboratory session: the stand-alone executable version of the determined emulation they need to automate and the student version of the development software, Step7, from Siemens, which also includes the computer simulation of the Siemens controllers, S7-PLCSIM.

Students are given an automation task to solve, in which they have to make an analysis of the process in order to gain ideas that take them to a correct solution. The implementation of this may be unsuccessful and a redesign will be required. This leads the students to try solutions on the emulation several times in order to reach the final one. If the laboratory session comes to an end before they have arrived at a correct solution, they can continue working outside the laboratory.

At the next laboratory session, the instructor tests the PLC program in the emulation and only when the program runs completely out of errors the students are asked to test it at the real system.

DEVELOPMENT TOOL

The software used to develop the Emulations is LabVIEW, from National Instruments. This development tool offers important advantages in comparison to similar simulation software, such as SIMIT from Siemens, DELMIA from Dassault Systems, COSIMIR from Festo and SPS-VISU from MHJ-Software, among others.

Whereas some are very complex and expensive tools, others are cheaper but not so flexible. None of them allows a massive distribution of the developed models, since a license needs to be purchased; even if it is only desired to use already developed emulations.

The main advantages of our development using LabVIEW are:

- Distribution: once an emulation has been developed, it can be distributed in a limitless way and

completely free of charge to the students. They just need to download LabVIEW-Runtime from the Internet; it can be installed without the need of a license.

- Portability: emulations can be used in computers running different operating systems. The development tool runs in diverse platforms such as: Windows, Mac OS, Solaris and Linux.
- ActiveX support: LabVIEW supports ActiveX functions. Although the emulations were developed to be used with Siemens software, they can be easily adapted to work with software from different companies that support ActiveX technology.
- OPC support: LabVIEW also supports OPC technology, which offers an open protocol for exchanging data between applications from different companies. With emulations, OPC technology can be used to control the emulations using PLCs from different providers. When emulations are controlled by real PLCs, students can build up and then validate the required hardware configuration of the PLC, complementing the entire process.

DEVELOPED LIBRARIES

The connection between the emulations and the simulated or the real PLC is achieved with a set of self-developed libraries, which make use of LabVIEW's ActiveX support. Depending on the desired connection (whether with a simulated or with a real PLC), an appropriate ActiveX control is used.

Besides, when working with real Siemens Controllers, the libraries allow the connection through almost all the PLC-supported industrial networks, such as MPI, PROFIBUS and Industrial Ethernet.

The libraries have been divided into five groups according to LabVIEW's programming standard: configuration, open, write, read and close section.

Furthermore, the error codes have been analyzed and prepared in such a way that, if a problem occurs, the user can easily find it out.

The libraries also take advantage of the polymorphic property, in order to write or read different data types with the same write or read function.

Figure 6 shows a typical connection with PLCSIM. Observe the way to write and read an entire input and output byte.

It is also possible to create new libraries that work with PLC environments from different providers, as long as the ActiveX technology is supported. It would be enough to select an adequate ActiveX control and continue the scheme followed until now.

STUDENT'S PERCEPTION

All students currently working with emulations were surveyed to discover what they thought about them. Students could rank each affirmation on a scale from 1 to 5; from highest score (Excellent) to worst score (Bad).

Results (see Figure 7) show that 77 per cent of students think that the emulations help them in an excellent way (score 5) to solve all of their assignments, whereas the remaining 23 per cent said that they only thought them very good (score 4). 84 per cent of the students believe that the emulations support the learning process at the laboratory in an excellent way (score 5), whereas the remaining 16 per cent only thought them very good (score 4). 84 per cent of the students believe that the emulations helped them to understand the concepts taught in class in an excellent way (score 5), whereas the remaining 16 per cent only thought they were very good (score 4). Finally, 65 per cent of the students believe that, in general, the use of emulations in automation laboratories is excellent, whereas the remaining 35 per cent think that it is very good.

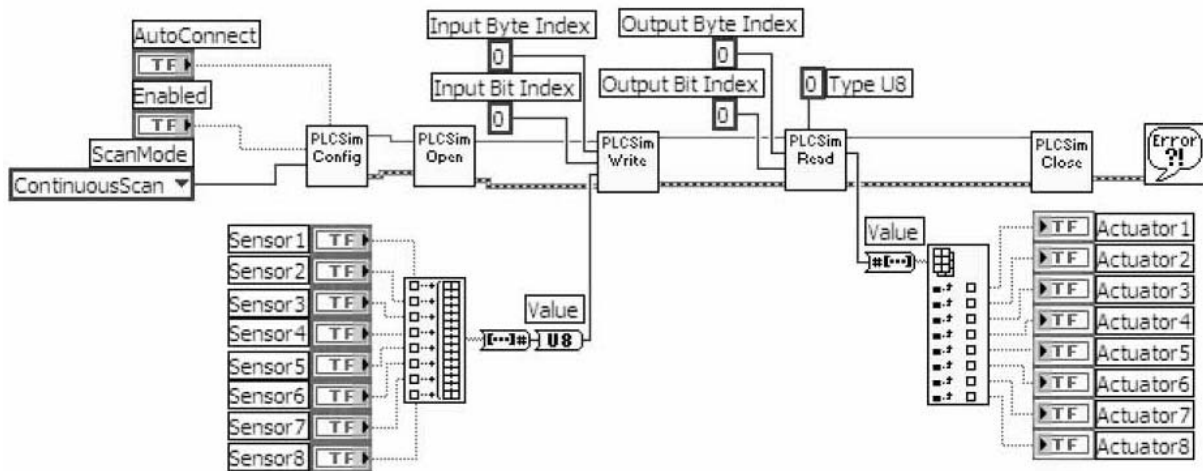


Fig. 6. Typical PLCSIM connection.

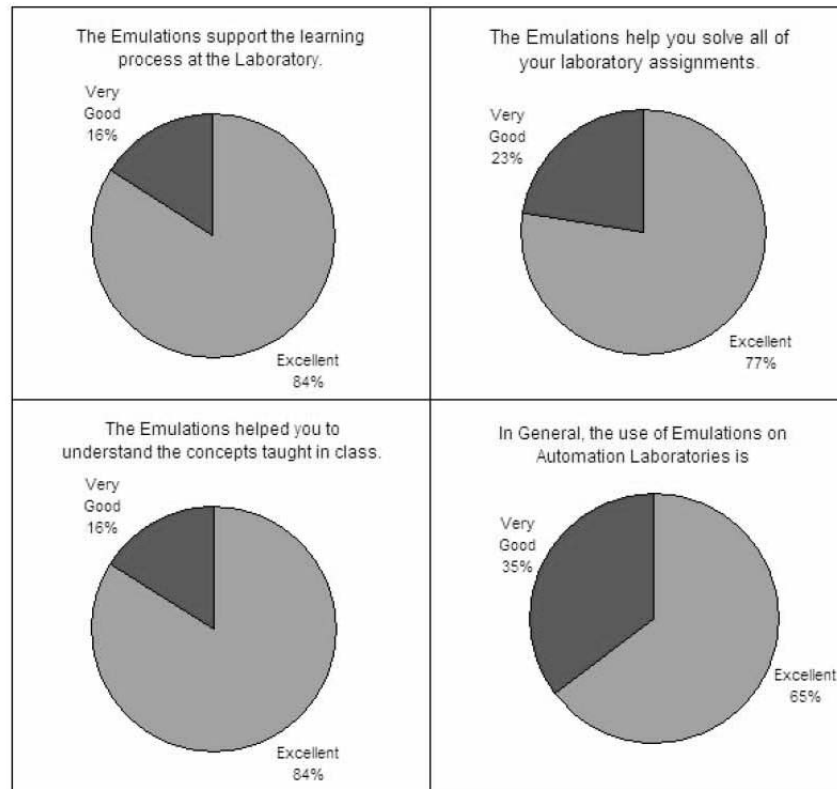


Fig. 7. Survey results.

It is important to emphasize that all of the results from the survey presented an Excellent (5) and Very Good (4) score; none of them received a score of 3 or fewer points.

CONCLUSIONS

Because of the high cost of appropriate laboratory equipment, one possible solution is to use computer emulations to support practical education and training.

Compared with similar simulation software on the market, referred computer emulations can be limitlessly distributed without restriction and without having to purchase any license.

By handing emulations to the students, the laboratory concept is extended. The students are then able to program, test and debug their PLC programs without being restricted to a laboratory session. The laboratory is therefore always available.

The results obtained have shown that the students

perform much better than in a traditional laboratory session. This fact has been confirmed after three years of using emulations as a part of the Tele-Engineering Lab at Monterrey Tech. The process has shown that the most important benefits are:

- Students solve the exercises in a more enthusiastic way, which influences directly their performance.
- Students accepted working with emulations and they are even pleased with its use, because they offer them more flexibility when solving their assignments.
- Students enhance their learning process and as a result they also increase their final grades.
- Instructors have said that it is much easier to review all of the exercises, since they can apply different tests to a student's program.

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REFERENCES

1. V. Fernández, Virtual Laboratories for Control Education: a Combined Methodology, *Int. J. Eng. Educ.*, **21**(6), 2005, pp. 1059–1067.
2. J. Liu, J. and R. G. Landers, Modular Control Laboratory System with Integrated Simulation, Animation, Emulation and Experimental Components, *Int. J. Eng. Educ.*, **21**(6), 2005, pp. 1005–1016.

3. Szczerbicka, Banks, Rogers, and Zeigler, Conceptions of Curriculum for Simulation Education (Panel), *Proceedings of the 2000 Winter Simulation Conference*, (2000).
4. A. Größler, Don't let history repeat itself—methodological issues concerning the use of Simulators in teaching and experimentation, *System Dynamics Review ABIINFORM*, **20**(3), 2004, p. 263.
5. M. Macías, I. Méndez, TeleLab—Remote Automations Lab in Real Time, *38th ASEE/IEEE Frontiers in Education Conference*, (2008).
6. M. Kezunovic, A. Abur, G. Huang, A. Bose and K. Tomsovic, The Role of Digital Modeling and Simulation in Power Engineering Education”, *IEEE transactions on power systems*, **19**(1), 2004, pp. 64–72.
7. W. Luo, J. A. Stravers, K. L. Duffin, Lessons Learned from Using a Web-based Interactive Landform Simulation Model (WILSIM) in a General Education Physical Geography Course, *J. Geoscience Educ. Bellingham*, **53**(5), 2005, p. 489.
8. K. Debevec, V. Kashyap, Learning Strategies and Performance in a Technology Integrated Classroom, *J. Research on Technology in Educ.*, **38**(3), 2006, p. 293.
9. M. Macías, Guridi, and Ortiz, TeleLab, Remote Laboratory for Automation and Control, *IFAC Conference on Cost Effective Automation IFAC-CEA* (2007).
10. Gomis, Montesinos, Galceran, Bergas and Sudriá, “A Chemical Process Automation Virtual Laboratory to Teach PLC Programming”, *Int. J. Eng. Educ.*, **23**(2), 2007, pp. 403–410.
11. B. Rodríguez, and Guzmán, A Virtual Course on Automation of Agriculture Systems, *Int. J. Eng. Educ.*, **22**(6), 2006, pp. 1197–1210.

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