Physical and Virtual Environment for Automation Education of Engineers and Technicians

Part 2: Laboratory activities in process control and automation through a virtual and physical environment

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Abstract

Nowadays, industrial software and communication tools allow the managerial staff, engineers and technicians to enhance the productivity and optimize automated production systems without the necessity of being physically on the production floor. In some instances, equipment providers can even assist plant engineers and technicians in troubleshooting specific equipments from a distant site, using advanced tools providing real-time information (visual, process data, etc.) from the plant.

The current project, through the use of recent industrial communication technologies, proposes the reproduction of a similar situation, in joint learning activities for future engineers and technicians. This kind of interaction, in an early educational context at both levels, is unique to the knowledge of the authors. The institutions taking part in this project are the Université du Québec à Rimouski (UQAR) and the Cégep de Rivière-du-Loup, located in eastern Quebec.

Two activities were initiated, the first as part of a process control course using a stand-alone physical setup, and the second using a currently designed mini-plant for recycling beverage bottles and cans as part of a sequential automation course. Results showed that the students at both institutions were able to work together and communicate effectively despite their different background. The training objectives for this phase of the project were successfully achieved and lessons learned will be further exploited to enhance the training level and student-acquired skills during the following phase of the project.

1 Introduction

Interaction with real systems is widely recognized as very important in control and automation engineering

education as it allows the students to better consolidate the theoretical concepts seen in class [1][2][3][4]. This commonly takes the form of local physical setups or simulation environments. However, actual automation technology now allows to control systems at a distance and often involve more complex situations implicating the exchange of real-time plant data, video streams of different plant sections, and even in some cases, the reception of process input commands and controller program modification from outside the plant. These technologies are often used by service and equipment providers (*e.g.* for distance troubleshooting), and given the actual trends on the global market, companies tend to integrate them to allow a better monitoring of plant performance and production even up to their higher management teams. Different levels of such “business intelligence” are becoming a significant advantage for the industries in the actually ever-changing business environment [5][6][7].

Ability to adapt to rapid technological changes is a required skill for our future graduates (both engineers and technicians). In order to best prepare our students for such challenges ahead, their formation also needs to constantly update on current technologies and future trends. In light of these observations, the Université du Québec à Rimouski (UQAR), the Cégep de Rivière-du-Loup (CEGEP) and the Premier Tech Company, a world leader in the field of bagging equipment, have decided to join forces in order to improve the training of future engineers and technicians in the field of Industrial Automation and Control. Globally, the aim of this project is to allow the university and CEGEP (college) students to join forces and work together on practical problems while being in two separate sites.

Related work involving distance learning or remote experiments can be found for example in [1]-[5][8][9]. However, these reports either involve entirely virtual setups [2]-[4][8], real distant setups with no operators in proximity [9] or synchronous collaboration between

students and a professor [3][4] for the transmission of knowledge. Our work is unique on three aspects: (i) it involves a synchronous collaboration between distant teams of students on a common problem (ii) it implies the interaction between student teams of two different levels of education (future technicians and engineering students) and (iii) students are given the opportunity to use cutting-edge industrial automation technologies in the context of real-time distance plant access.

As presented in the first part of this paper [10], the first phase of the project consisted in the design of an automated mini-plant for recycling containers. This mini-plant, designed and manufactured by engineering students at UQAR, was then installed in the CEGEP building, located ~100 km away from the University. The next steps were to build a virtual environment that would allow on-line process monitoring and real-time visualization of the mini-plant, develop a few training scenarios related to breakdown diagnostics, parameter adjustments, performance tests, security aspects, and process optimization.

This second part paper presents this environment set up for interactions between the students themselves and towards industrial equipment. It also describes the learning activities that have been experimented with the students at the two remote sites. It then provides an assessment of the satisfaction level from students and an impact evaluation of the learning activities. Finally, it presents a few concluding remarks and proposes intended improvements to the learning activities.

2 Communications environment

During the activities, different categories of interaction were expected to occur, which can be divided into two categories, namely “people-to-people”, and “people-to-equipment”. Such events were to be allowed both locally and distantly for the realization of the planned activities. In order to meet such requirements, suitable industrial communications equipment had to be deployed and properly configured.

People-to-people interactions are to happen in real-time (synchronous) and off-line (asynchronous) mode, depending on the activities stages. When present in the laboratory, UQAR students have access to a computer, a large videoconference screen, web cam, microphone, speakers and an Internet connection. CEGEP students, for their part, are physically present in close proximity to the industrial equipment related to the activity. They have access to a laptop computer equipped with all the abovementioned commodities (web cam, etc.), and a wireless Internet connection. All students use freeware Skype or VzoChat for real-time communications. The interaction video sequences (in VzoChat) are recorded

and can be viewed at will by the professors and other teaching team personnel, and can be used for student evaluation. To ease asynchronous communications, a specific email address was created for all individual student teams (both at UQAR and CEGEP). This also enables the teaching staff to keep a certain track of the communications between the student teams.

The videoconference technology being used was of Tandberg Company. A full videoconference mode was used at the start of the semester to present the project, and at the end to dress a global summary of the events.

To allow people-to-equipment interactions, a VPN (Virtual Private Network) bridge was instated between UQAR and CEGEP LANs (Local Area Networks) as a private connection over the Internet. This allow for a secure connection to the CEGEP industrial equipment and data for the distant (UQAR) student teams. All the communications were thus kept hidden from external interventions or interception of information from third parties. The programming of the CEGEP controllers (mostly from the Allen-Bradley CompactLogix series) was possible remotely at UQAR using the proprietary RSLogix5000 software. Monitoring of the systems was also possible remotely through the user interface software, programmed either under Factory Talk View Studio (Allen-Bradley) or InTouch (WonderWare).

Real-time visualization of the physical systems was possible through additional dedicated IP cameras (one for every selected setup or portion of the whole system), their video stream being accessible using any web browser software. Access was however protected by means of a username and password. A simplified view of the environment (both physical and virtual) between the distant site (UQAR) and installations site (CEGEP) is given in figure 1.

Since process control and automation applications require quick response times and high data throughput automation equipment, STRATIX 8000 switches were chosen at the core of the CEGEP Ethernet-IP network. These switches are good for handling the data traffic between the various sections of an automated system, and different access points to the network. Availability of the Ethernet-IP network is of crucial importance to ensure adequate operation of the automated system. At the time of its installation, precautions should be taken for all network components in order to minimize noise sensitivity, and possibility of perturbation occurrences. Failure to do so could be the cause of frequent and/or intermittent communication faults with the controllers and drives, which could even lead to complete system breakdown.

Figure 2 shows a detailed view of the structure and configuration of the CEGEP Ethernet network (around example sections of the mini-plant).

Figure 1. Simplified global view of the collaboration environment between UQAR and CEGEP

3 Process Control Experiment

The first attempted experience with the distance setup described earlier was during the autumn 2009 semester as part of a process control course (the first one on the subject for the UQAR students and the second one for the CEGEP students). Since the main objective of the course is the control of continuous systems, there was a need for a different setup from the (sequential) mini-plant described earlier.

On the other hand, the CEGEP already possessed hydraulic setups, made by Lab-Volt®, composed of a few valves, pumps, tanks and related sensors. Students at the CEGEP were already experimenting with these setups in their process control course, thus offering an interesting opportunity to further extend their use in a remote experiment context.

3.1 Description of the physical setup

As just mentioned, the physical setup available at the CEGEP is an educational setup manufactured by Lab-Volt®. More specifically, a single module is composed of one main stocking tank (typically filled with water), from which two independent training setups (the unit being two-sided) can be composed. Each setup is then equipped with a variable-speed motor driven pump, a pneumatic valve (with two possible configurations), a choice of cylindrical tanks (small and larger diameter), a level sensor (choice of either ultrasonic or capacitive measurement technology) and a flowmeter (ultrasonic or magnetic technology).

In short, this setup allowed for the implementation of different situations and/or control strategies, either monovariable or multivariable. Contents of the course, however, were limited to monovariable situations, as it was an introductory course to the field.

Figure 2. Network equipments and configuration for the interaction activities (CEGEP)

3.2 Learning situations

At the CEGEP, a total of four (4) physical setups were available. Since a total of 15 students were enrolled in the course at UQAR, it was decided to use all the four setups to limit the size of the teams. Also, each team was assigned a different problem to work on, in order to more widely explore the possibilities of the setups.

The chosen situations were: the level control of a large tank, the level control of a smaller (in diameter) tank, the control of a liquid flow stream measured with a magnetic flowmeter, and the control of a liquid flow stream measured with an ultrasonic flowmeter. All the controllers on the setups were identical, Allen-Bradley L32E CompactLogix processors, with both digital and analog I/O cards. UQAR student teams had to deliver the controller program and user interface, as well as to assist the CEGEP teams in successfully implementing the control algorithms to the physical system and user interface. The user interface program was built under the FactoryTalk software (Allen-Bradley).

The activity was articulated around the following situation scenario: UQAR student teams assumed the role of equipment providers, having just delivered and installed a physical system to a client, in this case a CEGEP student team. Programming of the controllers however remained to be done, as well as integrating the equipment in the client's production line.

For UQAR students, the activity was planned over a four weeks period. During the first week, students had to familiarize with the different process elements and the control objectives. They also began to work on their basic controller program (under RSLogix5000). At the end of week # 2, their two programs, being the basic controller program and the user interface (under FactoryTalk) were to be finished and delivered by e-mail to their clients. The third week was dedicated to a first interaction session between the two teams (using

the remote connection described earlier), where the client teams tested the programs they had received and troubleshoot any problems they encountered. UQAR students used this interaction opportunity with the real process to collect process data at different operation points in order to perform a thorough identification of the system and evaluate its nonlinearity. The data was then analyzed and processed by UQAR student teams between week # 3 and week # 4 interaction sessions. At week # 4, a final interaction session was planned, where the final troubleshooting was done and the PID control strategy was implemented and fully tested. At the end of this session, the system was thus considered end-delivered, fully automated and functional.

It has to be emphasized that at UQAR, during their course and prior to the activity, the students have been introduced to the programming of the L32E controllers (using RSLogix5000 in a first “local” laboratory) and user interface (using FactoryTalk in a second “local” laboratory). They also had the occasion to experiment with a hydraulic setup (with objective to control the level control of a cylindrical tank) in a third “local” laboratory, where they could also familiarize with few sensor technologies for level and flow, and actuators (pumps and proportional valves). Without such proper introduction, the interaction activities could not have been planned over a period of only four weeks.

3.3 Results and feedback from students

Results for this experimental activity were, in all, very positive. A general questionnaire (summarized in table 1) was elaborated on different aspects of the activity for the UQAR students. A total of 14 students (out of 15) took part in the evaluation of the activity.

On the subject of communication tools, students all felt that the software used was either highly (71%) or rather (29%) appropriate for the interaction activities. On user-friendliness of the tools, since most had never used Skype or VzoChat, only 36% found those to be very user-friendly, while 74% found them rather user-friendly. On the quality of communications subject, only one single student considered that the problems encountered were rather major, while 57% of the other students considered them rather minor. The remaining 29% of students considered the problems encountered as very minor or insignificant.

The automation tools used were considered of high importance (71%) or relevant importance (29%) in an engineering education program. However, 21% of the students did not appreciate the user interface software (FactoryTalk) and found it not very user-friendly. The remaining students still found it appropriate to learn as part of an engineering degree (79%).

The overall quality of interactions with the CEGEP teams was considered excellent (57%) or good (36%). Only one student considered it as passable. Their level of competence was considered either very high (79%) or rather high (21%). The global satisfaction of UQAR students about the overall experience was either very high (93%) or high (7%). All students considered that this activity definitely has its place in their formation.

Students and teachers at the CEGEP also evaluated the experience, but in the form of a group discussion instead of a questionnaire. What emerged from these discussions was that CEGEP students really liked the experience, and felt they were respected from UQAR students throughout the activity. However, they also felt there could have been more interesting exchanges of information on some details, such as the tuning methods used at UQAR versus the method they use at the CEGEP. A better definition of the exact roles of the students would be in order to improve the activity.

Table 1. General questions asked to UQAR students

1. Communication tools
What is your general appreciation of the tools used for communication with the CEGEP teams?
2. Quality and success of the communication
Did you experience any communication problems?
3. Automation tools
How do you judge the automation tools used and their pertinence in your engineering formation?
4. Team interaction and cooperation
What is your general feedback on the interactions and pertinence of this activity in your formation?
5. General appreciation
What is your general impression of the activities?
6. General comments
Please state any pertinent comments regarding the activities, suggestions for ameliorations, etc.

4 Sequential Automation Experience

During the winter semester of 2010, mostly the same groups of students were facing a new challenge in the industrial automation field. In more general courses on automated production systems, both engineering and technical-level students were given the opportunity to participate in the design, program and troubleshooting of real industrial situations. In the laboratory activities, student teams from UQAR and the CEGEP were both required to work together from their remote location, using the virtual environment presented earlier in this paper. Once again, the objective was to implement the automatic operation of specific process units, this time

on parts of the mini-plant designed for the recycling of beverage containers.

The idea behind the activity was to simulate client-supplier interaction, and allow students to experiment remote troubleshooting interventions. A physical setup was considered delivered and installed by each UQAR team (supplier role). Each CEGEP team assumed the role of a client. All units of the mini-plant were thus in place, with actuators and sensors calibrated. However, the automation of the system still remained to be done.

4.1 Description of the physical setup

Figure 1 shows the different units present in the mini-plant. The individual units are the washer and dryer units (not yet developed at the time of the experiment), the storage unit, the sorting unit, the can pressing and classification units and finally the bottle shredder unit. These individual units were arranged in three sections.

Figure 3. Mini-plant general sections

The first section of the mini-plant comprised both the storage and the sorting units. The storage unit is being composed of two carousels serving as cans and bottles rack, and two chutes to bring the containers onto the conveyor. The conveyor then takes the containers to the sorting unit, which separates the cans from the plastic bottles for appropriate further treatment.

A second section of the mini-plant consists in the combination of the shredder and weighting units. It is first composed of a chute leading the bottles into a swivel bottle holder in order to remove the label using a rotating steel brush. Then, the bottles are taken to the shredder section, where they are cut into small plastic pieces.

A third and last section comprises the pressing and classification units. The pressing unit has a conveyor that brings the containers to the press section, and a hydraulic cylinder to squeeze cans. The classification

unit is finally used to separate cans based on registered trademark.

4.2 Learning situations

All three individual mini-plant sections just described were given as separate projects to the three student teams of the course. Each required the development and implementation of SFC and Ladder programs that would respect the required sequences of the mini-plant units operations. The PLCs used in these applications are the CompactLogix L32E from Allen-Bradley. The actuators and sensors were chosen from a variety of technologies and styles making this mini-plant a very rich educational setup.

The activity lasted over 6 weeks, comprising four stages. The first stage was to take UQAR engineering students to the CEGEP for a first physical encounter with the technical-level students. During this visit, the project teams were formed and UQAR students were shown how every unit of the mini-plant works and should be operated. They were then provided with all useful documentation for the realization of the project (electrical plans, sensor data, etc.). The second stage was then for the students to establish the functional specifications of the units they were assigned, and then validate with their corresponding CEGEP team (acting clients). The third stage was to conceive and program the GRAFCET (SFC) and LADDER algorithms, and implement them into PLCs, taking into account recent advances in PLC and sensor technology. The future technicians, in turn, had to validate and correct the programs so to ensure the compatibility between the inputs and outputs being programmed and the physical system (as opposed to simply rely on information from the documentation). They also collaborated with the UQAR engineering students in troubleshooting the process in order to converge towards an efficient and optimal industrial operation system. The fourth and last stage was to arrange the virtual meeting between the two institutions students for final implementation and troubleshooting of their unit or mini-plant section.

4.3 Results and feedback from students

From observations, results of the experience show that engineering students at UQAR have developed useful knowledge and skills in PLC programming. The interactions with the technical-level students proved a great opportunity since it allowed them to develop critical thinking related to their experience and create efficient exchanges with them. At the technical level, the UQAR students have correctly provided programs that respected the required specifications, for all three

sections of the mini-plant. However, underestimation of the required time for the students to realize the tasks and inexact knowledge of the installations effectively in place at the CEGEP slightly hampered the activity.

A similar questionnaire to the one presented earlier was adapted to evaluate this second experiment. The results show that UQAR students were satisfied over 80% on the choice of communication tools and over 90% on the quality of communication. In the advent of computer/network problems, however, students have conceded their very limited knowledge on the subject (53%). Then, still about 90% of students believe that the automation software used is very relevant to their formation and felt that they became fairly competent in the use of these tools. On the quality of interaction and cooperation, there was again very good interaction between the students at the two sites.

To improve the quality of student interventions and to allow them to improve their learning and training in the industrial automation field, it could be beneficial to modify the approach in order to encourage more solid exchanges between the students at the two sites as well as elaborate into more detail each team's exact role so to converge towards a better and stronger constructive relationship between students at both institutions.

5 Conclusion

This article presented an environment that has been set up for synchronous distance collaboration activities between students of two different levels of education (university and college) around industrial automation equipment. It also described the learning activities that have been developed and experimented with the students at the two remote sites. It then provided an assessment of the satisfaction level from the students and evaluated the impacts of the learning activities.

Results showed that the students at both institutions truly appreciated the experience and demonstrated the ability to work together and communicate effectively despite their different backgrounds. Current training objectives were successfully achieved and the lessons learned will be further exploited to enhance the training level and student-acquired skills during the following phase of the project.

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