Physical and Virtual Environment for Automation Education of Engineers and Technicians

Part 3: Improvement of joint distant laboratory activities in process control and automation based on past experience

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Abstract

Current industrial software technology offers the possibility for the plant staff to operate production systems without an obligate need to be present on the production floor. Our project, which earlier phases were presented in the last CEEA conference, proposed joint learning activities related to this reality for the training of future engineers and technicians. It is a collaboration between the Université du Québec à Rimouski (UQAR) and the Cégep de Rivière-du-Loup (CEGEP), both located in the eastern Quebec region. Activities were conducted under two different themes: (i) process control activities using a hydraulic training setup, and (ii) sequential automation activities using individual units of a mini-plant designed for recycling beverage bottles and cans.

The third phase of the project, being the subject of this paper, was to improve the virtual environment and laboratory activities from past experience results, and evaluate the effectiveness of these modifications. To state a few modifications as examples, the activities contexts were modified from a customer-client relation between the teams to a more cooperative scenario, as distant and local implementation teams from the same service provider. The sequential automation activity was conducted on a more complete and operational mini-plant, and the student teams were involved in a more interactive work, involving exchange of files and sharing common work objectives. All activities started with a physical encounter between the student teams, which effectively helped to improve comradeship.

Results once again showed that students from both institutions successfully worked and communicated together despite their different skills and backgrounds. Training objectives for this phase were successfully attained and the lessons learned were exploited to effectively enhance the training level and the student-acquired skills through the activities.

1 Introduction

In engineering education, it is commonly agreed that interaction with real systems is of high importance, as it allows the students to better link theory and practice [1][2][3][4]. This is of course also true in automation, where local physical setups and simulators often serve as a base for laboratory activities. While these remain highly important, current automation technologies also offer interesting possibilities such as systems control from a distance (including the real-time access to plant data, live video feeds, etc.). These are often involved in distance troubleshooting by service and equipment providers. Recent trends on the global market also lead companies to integrate similar tools up to their higher management, providing them with an almost real-time feed of plant performance and production. This proves to be a significant advantage for industries in an ever-changing business environment [5][6][7].

As technological changes are occurring fast in the current world, the ability to adapt quickly is a required skill for future graduates (engineers and technicians). An adequate formation has to be provided, constantly up to date on current trends and technologies. These observations prompted the Université du Québec à Rimouski (UQAR) and the Cégep de Rivière-du-Loup (CEGEP) to join forces in order to improve the training of future engineers and technicians in the field of Industrial Automation and Control. Along with the support of Premier Tech, an industrial partner and world market leader of bagging equipment, a project was set up to allow students from both institutions to train using cutting-edge automation technology and equipment and collaborate on practical problems while being in two distinct 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. The uniqueness of our work lies on three aspects: (i) it involves a synchronous collaboration between distant students teams to work on a common problem; (ii) student teams involved are from different levels of education (future technicians and engineers) and (iii) students are given the opportunity to use cutting-edge industrial automation technologies in the context of real-time remote plant access.

As presented in our previous papers [10][11], the early phases of the project consisted in designing and manufacturing the recycling mini-plant. This was done by engineering students at UQAR, then it was installed in the CEGEP building, about 100 km away from the University. Next, the virtual environment that would support the activities (on-line process monitoring, real-time visualization of the mini-plant, etc.) as well as the training activities themselves were elaborated and first tested.

This third part paper first gives an overview of the physical and virtual setups involved, then presents the activities into more detail, putting into perspective the modifications that were made based on the previous experiments. It is followed by an assessment of the student satisfaction level and training issues, including a comparison with the results from the previous year. Finally, concluding remarks and further last intended adjustments to the learning activities are presented.

2 Communications environment

The environmental setup needed to support two types of interactions for the activities: people-to-people and people-to-equipment. These were to be allowed at the two sites, both locally and remotely for the events to occur effectively. People-to-people interactions were planned to happen in real-time (synchronous) and off-line (asynchronous) modes, depending on the activities stages. Suitable industrial communications equipment (hardware and software) were to be properly installed and configured to meet these requirements.

In the laboratory, UQAR students have access to a computer, a large videoconference screen, a web cam, a microphone, speakers and an Internet connection. CEGEP students on their part, work in close proximity to the industrial equipment related to the activity. They have access to a laptop computer equipped with all the abovementioned commodities, and a wireless Internet connection. All students used the freeware Skype for the real-time communications. For the asynchronous communications, a specific Google group account was created for all the student teams (both at UQAR and at

the CEGEP). Each group also included all the teaching staff involved, which helped them to keep track of the communications between the student teams.

People-to-equipment interactions occurred through a « VPN » (Virtual Private Network) bridge, instated between UQAR and CEGEP « LANs » (Local Area Networks), as a private connection over the Internet. This way, all communication between the CEGEP industrial equipment and data for the distant (UQAR) student teams were secured and hidden from external interventions or interception of information from third parties. The CEGEP controllers, mostly Allen-Bradley CompactLogix L32E, were allowed to be programmed remotely from UQAR using RSLogix5000, an Allen-Bradley proprietary software. Systems monitoring was also achieved remotely through HMI (human-machine interface) software (InTouch, from WonderWare).

It was possible to visualize the physical systems in real-time through dedicated IP cameras (one for each pre-selected setup or portion of a whole system). Their video streams were accessible using any standard web browsers available. Access was however protected and granted upon the use of a username and password. A schematic representation of the environment (physical and virtual) between the UQAR and CEGEP sites is provided in Figure 1.

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

3 Process Control Experiment

Process control courses having to deal with continuous systems, a different set-up from the (sequential) mini-plant is required to adequately relate to their specific objectives. Distance experiments in this context were thus conducted on Lab-Volt® hydraulic training setups available at the CEGEP, which comprise a variety of valves, pumps, tanks and related sensors such as level and flow. CEGEP teams had already experimented on

this setup locally, prior to the interaction activities. A more complete description of the physical system is provided in [11].

As also discussed in [11], the interaction activities occur as part of a second process control course for the CEGEP students, and as part of a first process control course for UQAR students. Since it is an introductory course in their formation, experiments with the system are limited to simple monovariable PID loops, though it would easily allow more complex control strategies and structures to be implemented.

The semester of Autumn 2010 was the second time the activity was initiated. Results from the first attempt in Autumn 2009 were used to improve the activity, on aspects such as better collaboration between teams and facilitate the focus on the course objectives rather than the technical difficulties (*e.g.* software issues, network communications problems, etc.).

3.1 Learning situations and improvements

A maximum of four (4) physical setups were available at the CEGEP to conduct the activity. As a total of 15 students were enrolled in the course at UQAR in 2010 (the exact same number as in 2009), it was decided all the setups would be used to limit the size of the teams. It is acknowledged, however, that teams including four students are less than ideal.

All teams were assigned different situations to deal with, so to minimize the risk of plagiarism and allow a wider exploration of the possibilities from the setups. Those situations were: the level control of a large tank, the level control of a small (diameter) tank, the control of a (liquid) flow stream using a magnetic flowmeter, and the control of a flow stream using an ultrasonic flowmeter. Controllers on the setups were all identical, Allen-Bradley L32E CompactLogix processors, with digital and analog I/O cards.

In 2009, UQAR students had to develop the entire controller program and user interface, and then assist the CEGEP teams in successfully implementing them on the physical system. At the time, some members of the CEGEP teams felt they were not used to their full potential, often idle instead of actively participating in the project. In the actual (2010) version of the course, both sides were asked to develop either the controller program or user interface, in a collaborative manner.

In 2009, the user interface program was built under the FactoryTalk software (proprietary Allen-Bradley). This year, the program was switched to InTouch (from Wonderware) as it is easier to learn over a short period of time.

In 2009, the UQAR student teams assumed the role of equipment providers, while the CEGEP teams were assuming the role of a client. However, the experience

has shown that such a setup did not much encourage collaboration. This year, it was thus decided to modify the relation between the teams as two implementation teams (distant and local) from a same service provider.

The planning of the activity was once again over a period of four (4) weeks. However, this time, students from UQAR were brought to visit the CEGEP site and meet their “co-workers” during the first week. Basic procedures for operating the systems (*e.g.* Start-Stop sequences, safety issues, etc.) were presented to the students, and they had a live opportunity to see the systems running. Students teams also were to begin to discuss automation issues (*e.g.* determine the variables to appear in their programs, tag names, etc.), to ensure their programs compatibility.

Week # 2 was planned for the teams to separately work on the development of their programs. At this stage, exchange of email communications for specific updates or discussions concerning the programs were possible. Both programs were to be completed before the first interaction session scheduled in week # 3. The implementation and troubleshooting of the programs was to be done during this session, in addition to the acquisition of process data that would allow system identification. Data was to be analyzed and processed by UQAR students to determine the appropriate PID control parameters, prior to week # 4 final interaction session. This last session was dedicated to the final troubleshooting of the programs and implementation and validation of the control strategy onto the physical system. After this, the system was to be considered fully delivered, automated and functional.

It has to be emphasized that in order to adequately prepare UQAR students for the activity, they had to be introduced to the programming of the L32E controllers (using RSLogix5000 in a first “local” laboratory) and the user interface (using “InTouch” in a second “local” laboratory). They also had an opportunity to operate a hydraulic setup in a third “local” laboratory, and learn about sensor technologies for level and flow, as well as actuators (pumps and proportional valves). Without such an introduction, the interaction activities could not have been planned over only four weeks.

3.2 Results and feedback from students

To allow comparison, the same questionnaire from last year was used to survey the UQAR students on many aspects of the activity (summarized in Table 1). The results were globally positive. All the 15 students from UQAR were able to attend the evaluation activity (this puts the percentages into perspective).

About the communication tools, the results in 2010 were similar to 2009, as all the students felt they were either highly (~70%) or rather (~30%) appropriate for

the interaction activities. Also, about 40% of students considered them as very user-friendly, and about 60% as rather user-friendly. Quality of the communications was considered best in 2010 than in 2009. About 53% of students considered that the problems encountered were very minor or insignificant, compared to 29% the previous year. These were considered rather minor by 40% of students (compared to 57% in 2009) and again only one student considered they were major ones.

Table 1. Survey questions for 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 (answer for each tool)
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.

The importance of learning these automation tools as part of their formation was rated high or rather high by a strong majority of students (93%). Also, although the user interface software was changed to a more user friendly one (InTouch instead of FactoryTalk), 20% of students still did not appreciate it. In the opinion of the authors, this could be due to a change in the computers exploitation system at the beginning of the semester, which resulted in a communications problem between InTouch and RSLogix5000. By the time the problem was resolved, the students did not have enough time to successfully implement a user interface on their own, which might have contributed to this situation.

Quality of the interactions with the CEGEP student teams was rated excellent by 73% of students (versus 57% in 2009). However, since a personal conflict has developed inside one of the teams, all members from this team rated the collaboration as poor or very poor. Being asked on the level of competence attained after the activity (and preparatory activities), a similar result as the previous year (~90%) felt they were highly or sufficiently competent with the industrial controller programming software. However, this rate fell to 53% regarding the user interface software, probably for the same reason mentioned earlier. In 2009, this rate was 85% with FactoryTalk, despite its higher complexity.

Student satisfaction about the overall experience was either very high or high (~90%). All students once again considered this activity definitely has its place in their engineering formation.

Students and teachers at the CEGEP also evaluated the activity, again as part of a group discussion instead of survey questions. Observations from the teaching team were that communications effectively improved as compared to last year, and so did the collaboration between student teams. Good information exchanges were made between teams, and most students felt they were well respected throughout the activity. One thing that was noted, however, is that there is sometimes an important difference between the teams regarding their skills with the tools. This could be attributed to the fact that UQAR students are often already qualified technicians before undertaking an engineering degree, or had at least one opportunity to work on controller programming as part of a summer internship, while the others had no prior experience or knowledge.

4 Sequential Automation Experience

This activity took place in the 2011 winter semester, as part of an automated production systems course. Again, two local and distant teams were set up for interaction in the context of remote intervention and debugging. The physical system used was the mini-plant for recycling beverage bottles and cans, which is complex enough to make an interesting challenge for students on sequential automation issues. Four units of the mini-plant were available for the experience.

Figure 2. Mini-plant sections

Objectives include the successful development and implementation of SFC (GRAFCET) and LADDER programs, complying with the specifications of logical and sequential operation of a given mini-plant unit. PLCs used for this application are the CompactLogix series from Allen Bradley. The mini-plant includes a

variety of actuators such as AC motors, pneumatic and hydraulic cylinders, etc., and features sensors such as proximity, capacitive, inductive, limit switches, etc. It allows students to familiarize themselves with several instruments and technology employed widely in the industry.

4.1 Overview of the physical setup

As shown in Figure 2, the mini-plant is made up of a washer and dryer unit, a storing and sorting unit, a can pressing and classification unit, and finally a bottle shredder unit. A complete description of all these units is given in [11]. These were all completely operational this year, while only three of them were available the last time.

4.2 Learning situations

The experiment formulation from last year implied the student teams each had to develop the entire program for a unit. However, the results analysis from last year revealed it was asking much of UQAR students to start programming from blank. Other issues that had to be addressed this year were: the communication tools and networks problems, and the total allotted time for the realization of the tasks [11].

This year, the experiment was thus conducted over a period of five (5) weeks (3 hours/week) and a series of individual steps were identified for the realization of the experience. The first step was to take the UQAR students to the CEGEP site in order to establish a first contact with the technical-level students. At this time, the general objectives of the activity were presented to the students, and the individual units of the mini-plant were explained into detail to the engineering students, including live demonstrations. UQAR students were also provided with technical documentation regarding the installations and specific equipment.

As a second step, UQAR students were required to understand (i) all the functional specifications of their assigned unit and (ii) a primary version of a program provided by CEGEP students for its automation (over two periods, for a total of 6 hours). In parallel, they were taught the theory on sequential automation, PLC technologies, programming strategies and a few case studies.

During the third step, student teams met again in person (this time at UQAR), where they participated in a problem solving session, and aimed to improve their programs (three hours). The last step was to finalize the programs, and hold one last virtual meeting (three hours) for their final implantation and troubleshooting and ensure the module is in good working order.

4.3 Results and feedback from students

A similar survey to the one presented earlier has been adapted for the evaluation of this second experiment. A total of 13 students participated in this activity, and 12 were available for the evaluation. Results show that students were satisfied with the communication tools used and the quality of communication throughout the experience (83%), in a similar fashion as the previous year (75%). It was however noticed that our students had a more limited knowledge of computer networks (25% felt they had major problems) than those of last year (0% felt so, even though problems were worse in the eyes of both teaching teams).

The majority of students again agreed the activity helped improve their skills with the automation tools (92% in 2011 versus 87% in 2010). Interaction quality and cooperation between the teams was similarly good as the year before (50% versus 37% felt it was perfect, 42% versus 50% felt it was good, and 13% versus 8% felt it could be better) despite the modifications made to help improve comradeship. It is thus felt that there remains room for improvement. Finally, the students considered that this activity is a very good experience and should be kept as part of the course.

On the CEGEP side, the students and teachers also evaluated the activity, and the main observations were that improvements were indeed made since last year, and students were more ready to undertake the project. The quality of teamwork was also improved, though for some teams, motivation seems to have lacked at times. The preparatory assignments should have been realized more seriously for certain teams, while some teams composition could have been more carefully balanced. However, the global activity was considered a success.

Engineering students have indeed developed strong knowledge and skills regarding automation. They have mastered the SFC and Ladder languages through PLC programming and troubleshooting and addressing complex problems. Interactions between students from the CEGEP and UQAR proved a great opportunity for them to develop teamwork skills. Finally, the students learnt to correctly provide programs that comply with the requirements for all units of the mini-plant.

5 Conclusions

This article presented improvements to synchronous distance collaboration activities using a physical and virtual environment for students from different levels of education (university and college) around industrial automation equipment. A description of the learning activities and the evaluation results were included. The

satisfaction level from students and the impacts of the learning activities were assessed.

Results once again showed that students from both institutions succeeded in working and communicating together despite their different skills and backgrounds. The training objectives were successfully attained and the lessons learned were effectively used to enhance the training level and student-acquired skills through the activities.

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References

- [1] I. Calvo, M. Marcos, D. Orive, and I. Sarachaga, "Building Complex Remote Learning Laboratories", *Comput. Appl. Eng. Educ.*, Wiley, vol. 18, no. 1, 2010, pp. 53-66.
- [2] E. Tanyildizi, and A. Orhan, "A Virtual Electric Machine Laboratory for Effect of Saturation of the Asynchronous Machine Application", *Comput. Appl. Eng. Educ.*, Wiley, vol. 17, no. 4, 2009, pp. 422-428.
- [3] C.A. Jara, F.A. Candelas, F. Torres, S. Dormido, F. Esquembre, and O. Reinoso, "Real-time collaboration of virtual laboratories through the Internet", *Comput. Educ.*, vol. 52, 2009, pp. 126-140.
- [4] C.A. Jara, F.A. Candelas, F. Torres, S. Dormido, and F. Esquembre, "Synchronous collaboration of virtual and remote laboratories ", *Comput. Appl. Eng. Educ.*, vol. 19, n/a. (to be published)
- [5] R. Zavbi, and J. Tavcar, "Preparing undergraduate students for work in virtual product development teams", *Comput. Educ.*, vol. 44, 2005, pp. 357-376.
- [6] J.O. Chan, "Real-time value chain management", *Commun. Int. Inf. Manage. Assoc.*, vol. 7, no. 3, 2007, pp. 79-88.
- [7] L. Wang, W. Shen, P. Orban, and S. Lang, "Remote Monitoring and Control in a Distributed Manufacturing Environment", in *Condition Monitoring and Control for Intelligent Manufacturing*, L. Wang, and R.X. Gao, Eds. Springer Series in Advanced Manufacturing, London, 2006, pp. 289-313.
- [8] J.S. Liang, "Design and Implement a Virtual Learning Architecture for Troubleshooting Practice of Automotive Chassis", *Comput. Appl. Eng. Educ.*, vol. 18, no. 3, 2010, pp. 512-525.
- [9] E. Scanlon, C. Colwell, M. Cooper, and T.D. Paolo, "Remote experiments, re-versioning and re-thinking science learning", *Comput. Educ.*, vol. 43, 2004, pp. 153-163.
- [10] J. Brousseau, D. Paradis, A. El-Ouafi, and S. Loubert, "Physical and Virtual Environment for Automation Education of Engineers and Technicians - Part 1: Engineering an Automated Recycling Facility for Bottles and Cans", *Proc. 6th CDEN Int. Des. Eng. Conf.*, Hamilton (ON), July 27-29 2009.
- [11] J-S. Deschênes, N. Barka, D. Paradis, M. Michaud, S. Loubert, and J. Brousseau, 2010, 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, *Proc. 1st CEEA Conf. Eng. Appl. Comput. Algorithms*, Kingston (ON), June 7-9 2010.