Complementary Simulation and Remote Laboratory Experiences to Hands-on Control Systems Curriculum

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Abstract — *Hands-on experimental approaches to learning are enhanced through the use of simulation and remote laboratory experiments. A hands-on approach continues to be integrated into the engineering curriculum through industrial collaborations as well as physical system experimentation in a control systems curriculum. Hands-on laboratory equipment comprising a large set of project-centered modules for experimentations uses off-the-shelf experimental control products of physical plants for engineering education. Extending regional efforts into an effort of international cooperation between the University of North Florida (UNF) and Cologne University of Applied Sciences (CUAS) gains the synergy of international engineering education through collaborative projects in precision automatic control engineering and the use of remote laboratory experiments with additional physical plants. The use of remote laboratories as online exercises introduces physical systems plants to experiments in control systems that are otherwise unavailable while also presenting a new and different approach to learning for the students. The premise for the Remote Laboratory, or RLab, is to allow a user from any location to access and perform tests on different experimental electromechanical plants. The user may access RLab from anywhere in the world with the only requirement needed is an internet browser. Additionally simulation tools and simulation validation increases the learning experience for the students. RLab, developed using commercially available software, has been used successfully at CUAS with three electromechanical plants and has also been ported and integrated with new sets of electromechanical plants at UNF. Data are collected regarding student learning experiences in a pilot study of the system dynamics and control curriculum. This paper describes the integrated approach and comparison of the use of simulation, hands-on experiential learning, and the incorporation of remote laboratories into the engineering curriculum.*

Index Terms — *Control system experiments, hands-on learning, remote laboratory, simulation.*

INTRODUCTION

Traditional hands-on methods of engineering education remain very valuable, however, today's growing technology allows new ways of education for future engineers. One of the attractive growing technologies enables users to run experiments via internet with minimized constraints of when or where. The advantages for engineering education includes the reduction of the need to own too many costly educational control plants and the reduction in the need for limited space in the laboratories. Technologies are needed that allow access to the equipment which would be unavailable otherwise and can be used by students wherever and whenever necessary.

Hands-on approaches continue to be integrated into engineering curricula through industrial collaborations [1] as well as physical system experimentation [2]. The concept of a remote laboratory has been used for instructional purposes in many instances and many examples exist. With the ability of the internet to allow users to connect and share common interest and resources, remote laboratories may be designed and implemented to produce a system which functions as a teaching method and/or a remote control via the internet. A remote laboratory may be used for instructional purposes in a variety of educational laboratory and remote control domains; for example, in power conversion laboratory [3], and in control engineering courses [4]. Remote laboratories have been developed for motion control in mechatronics [5], DSP control [6], electric drives [7], control of DC motors [8], industrial electronics [9], electrical components [10], and robotics [11]. Additional remote laboratories have also been developed for vibrations [12], signal analysis [13], microprocessor [14], costly laboratory equipment [16] using LabVIEW [17], robotics [18,19] and physics [20].

The primary technology basis of this paper is the result of an international collaboration effort between the Cologne University of Applied Sciences (CUAS) and the University of North Florida (UNF) and uses National Instruments commercially available LabVIEW software. Extending regional efforts into an effort of international cooperation between the University of North Florida and Cologne University of Applied Sciences gains the synergy of international engineering education through collaborative projects in precision automatic control engineering [21]. One motivation is to allow users at various sites, with differing hardware resources, to connect and share resources with colleagues via

remote access. With this motivation a Remote Laboratory, or RLab [22-25] has been developed using LabVIEW. Remote laboratories can be designed and implemented to produce a system which functions as a teaching method for control theory via the internet [22,25] in a project-oriented context. Further collaboration involves learning, using, developing, and enhancing the RLab Remote Laboratory System developed at CUAS [22-25], porting the RLab capability to UNF, and expanding the scope of experiments [21, 26-29].

BACKGROUND

The UNF Mechanical Systems Laboratory is a well equipped laboratory with Educational Control Plants (ECP) [26]. There are actually four types of ECP experimental plants at UNF. These are the 205 Torsional Plants, the 210 Rectilinear Plants, the 220 Industrial Plants, and the 750 Gyroscope. One of these, the 210 Rectilinear Plant, is the first plant used in the Mechanical Systems Laboratory which allows students to have fundamental understanding of systems dynamics identification which is then extended to control theories and implementations. Figure 1 shows the ECP 210 Rectilinear Plant.

The capabilities of the ECP plants form the basis of Project-Centered Modules, or PCMs in courses of system dynamics and control [2,21,29]. There are multiple replicas of these plants and suites of hands-on experiments for them at UNF, and because the experimental plants are from the same vendor, uniform issues for interfacing for all the plants helps to facilitate the migration into the RLab environment. The integration is also facilitated by the ECP-RIO and FPGA interface features made available through the LabVIEW and National Instruments [17]. This hardware and software architecture permits a configurable interface with customization tools featured within the LabVIEW system.

FIGURE 1
ECP 210 RECTILINEAR PLANT AT UNF

In the Mechanical Systems Laboratory there are multiple rectilinear plants available for hands-on laboratory instruction. Groups of three or four students, randomly selected by the laboratory teaching assistant, are assigned pre-laboratory questions which included some research about the experiment to be done as well as calculations necessary for the experiments. During the laboratory time, group members discuss their calculations and run the hands-on experiments.

The initial version of RLab [22-25] has been developed to enable a set of experimental plants at CUAS in Germany to be controlled remotely among partnering institutions. The additional capability of the RLab system is the ability to be solely run over the internet and thus allow it to be remotely accessed with the only requirement is that the user has a web browser. The development of RLab requires connecting the user to the experimental electromechanical systems. The website interface initiates the experimental system plant, records the data from the plant, and displays the results. LabVIEW software is used as the infrastructure largely due to its data acquisition capabilities and its internet connectivity options. Also a database is needed to monitor user activity and other experiment support functions. Microsoft Access is used to store the experimental data and other data. Some of the data include information for the login system that requires the user to sign up for RLab, login and logout times for the different users, and administrator information. Later releases of LabVIEW enable new features of the underpinning software, LabVIEW, to be incorporated into system enhancements while also allowing the introduction of new electromechanical plants.

The main purpose of RLab is to be able to run experiments on physical plants via internet. The way RLab works, a login username and password needed is provided from CUAS. The next step is to login and reserve the experiment time in order to have exclusive access to the system. For the initial RLab exercises in the Mechanical Systems Laboratory it was decided to use the Twin Rotor Plant located in the CUAS Control Systems Laboratory. Figure 2 shows the Twin

Rotor Plant. Originally, the Twin Rotor is used as Multiple Input Multiple Output (MIMO) system but the experiment at CUAS is adjusted for the system to be a Single Input Single Output (SISO) system by running experiments on a single independent axis.

FIGURE 2
TWIN ROTOR PLANT AT CUAS

METHODOLOGY

The aim is to compare and contrast the potential for remote laboratory experiments versus hands-on plant experiments by using survey results taken from UNF mechanical engineering students for complementary work done as part of their system dynamics and control curriculum. In the Fall 2009 semester, a complementary project module has been added using the remote laboratory approach to the Mechanical Systems Laboratory curriculum. Mechanical Systems Laboratory is a one credit, senior student level class, offered at UNF. The laboratory is designed to be a parallel co-requisite to a three-credit Control of Machinery course. The laboratory class size is small allowing hands-on emphasis to dynamics and control experiments. Of the sections used for this pilot study comparison, one of the sections included fifteen students and other section included thirteen students.

In the hands-on modules of the Mechanical Systems Laboratory two ECP 210 Rectilinear Plants were used. The procedure was to use the plants to perform dynamic systems identification and once that was done then PD/PID controllers were designed, simulated, and evaluated. With the controls class students use their classroom knowledge, analysis, and simulation results to calculate parameters to be implemented on the ECP plants in hands-on exercises of the Mechanical Systems Laboratory.

The RLab module added to the laboratory involved setting up the PD/PID controller parameters so students could observe the differences by running step response to the remote laboratory system. In this case, MatLab [30] simulations are used in pre-laboratory exercises to gain insight into the system behavior. After finishing the RLab experiment, results achieved from the computer simulations using MatLab and Simulink were compared to the results achieved from RLab. Then short reports were written by students. At the end of the semester students who participated in the RLab experiment took a survey on RLab versus hands-on plant experiments as well as the simulation tools. The data gathered from a survey questionnaire are used in the results below.

RESULTS

The approach taken in the pilot study of the Mechanical Systems Laboratory had two parts. First part was to simulate the adjusted Twin Rotor plant by using MatLab or Simulink and the second part was to actually run the experiment through the RLab website via internet. Of the students who took the RLab survey concerning control systems, more than half of them agreed that simulation done by using MatLab or Simulink helped students understand the dynamic system behavior of the actual hardware better. It also helped students observe the stability of the control experiment. A series of questions were posed to extract the information regarding the benefit of simulation and remote laboratory experience to supplement the hands-on approach to experimentation. As seen in Figure 3, while 23% of the students did not denote any opinion, 59% of the students agreed or strongly agreed that MatLab or Simulink simulations helped them visualize the dynamic system behavior of the actual hardware. The majority of the same group of students also agreed or strongly agreed that MatLab and Simulink are great simulation tools for understanding control systems.

Figure 3 shows the pie chart of the response to the statement: "MatLab/Simulink is a great tool to use for understanding control systems."
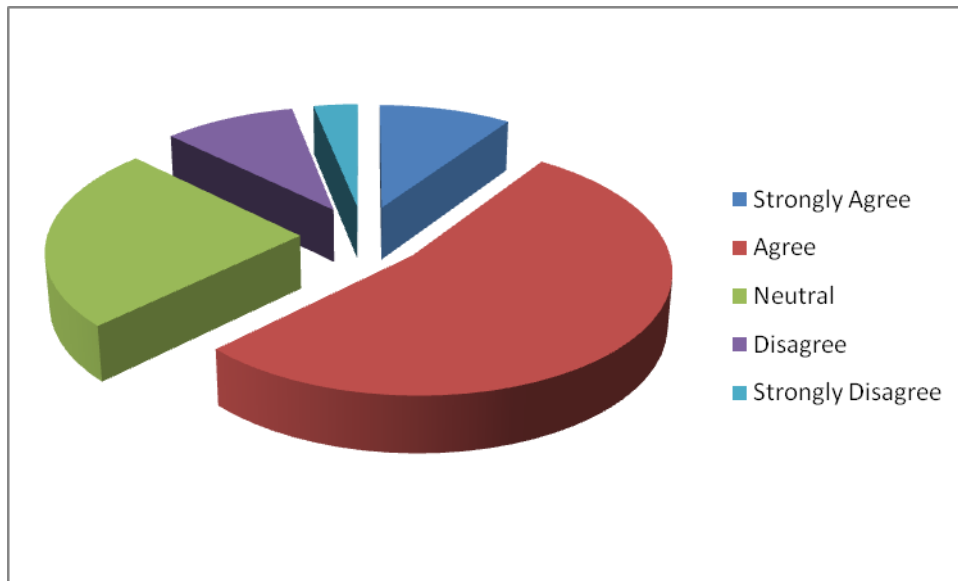
FIGURE 3
RESPONSE TO SIMULATION QUESTION

There were a few complications faced during the RLab portion of the remote laboratory module. One of the problems faced in the RLab module was that originally the Twin Rotor plant is a Multiple Input Multiple Output (MIMO) system but the system is adjusted for a single-axis to use the system as a Single Input Single Output (SISO) system. When the RLab experiment started the students were able to achieve matching results with the simulations. After the fourth group the Twin Rotor plant started to behave as a MIMO system with dynamically coupled axes of motion, which affected all the experiment results and those results did not match with the MatLab or Simulink simulation results. After this point interaction from the host site was necessary to reset the experiment. Figure 4 explains that the results obtained from RLab experiment for some participants did not match with the simulations done by using MatLab or Simulink in that 28% agreed while 38% were neutral.

Figure 4 shows the pie chart of the response to the statement: "The results obtained from RLab experiment matched with the simulations done by using MatLab and/or Simulink."
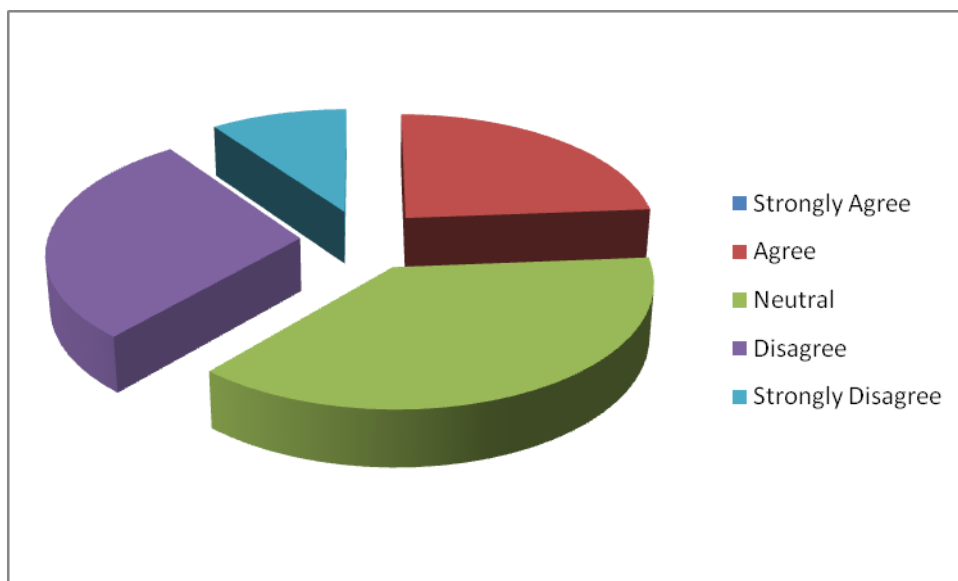

FIGURE 4
RESPONSE TO SIMULATION WITH REMOTE LABORATORY QUESTION

As can be seen from Figure 4, many students were able to match experimental results from previously developed simulation results, but not all of them. Another problem was that when there is an issue with the website, somebody at CUAS needed to be contacted. Because of the time differences between two countries this communication created delay. This issue prevented some students to complete the RLab portion because during the laboratory time the login user name and passcode would not work so students were not able to login to the website and run the experiment. The issue later was resolved. Another problem faced was that the two schools were using different versions of Java which led to problems for students at UNF to view the camera function. Not having visual reference had some negative impact on the success of the experiments. The students agreed that without the camera, RLab was still a useful tool for control systems. According to the students, the experiment however did not make as much sense without visualizing the plant. The problems with the camera contributed to this conclusion as well as the fact that the problems were not being able to resolve quickly due to the time difference between the United States and Germany.

Not surprisingly, the students surveyed agreed that direct hands-on experimentation was advantageous compared to the use of remote experiments. On the other hand students were very enthusiastic about the idea of running the Twin Rotor experiment remotely on another continent. According to their survey response they found RLab very interesting to work with and that use of the remote laboratory increased their understanding of control systems. Over 70% of the students agreed or strongly agreed that RLab is interesting to work with.

Figure 5 shows the pie chart of the response to the statement: " RLab is Very Interesting to Work With."
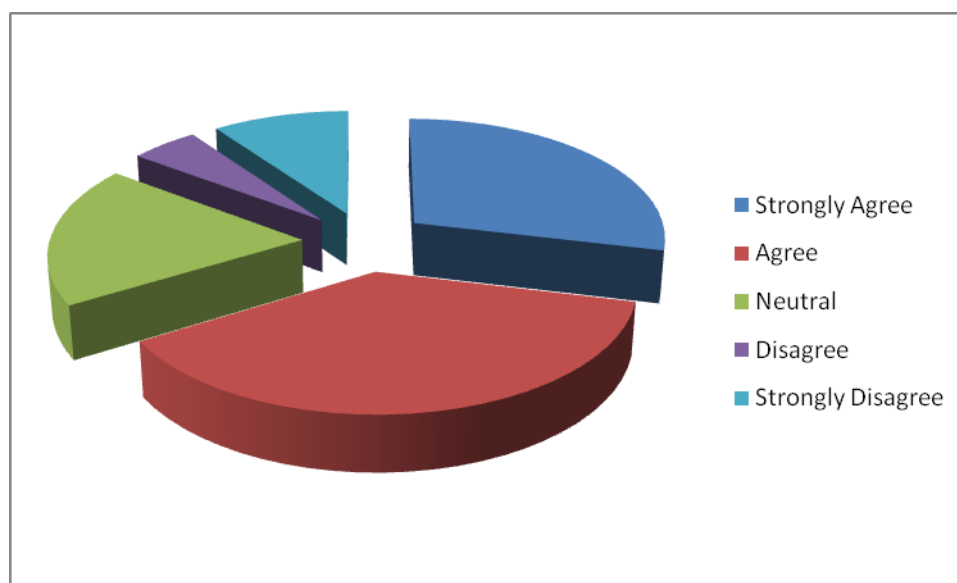

FIGURE 5
RESPONSE TO REMOTE LABORATORY QUESTION

CONCLUSION AND FUTURE WORK

An initial pilot study comprised of complementary simulation and remote access to experiments was included as a project-centered module in a curriculum for experimentation in dynamic systems and controls. After involving mechanical engineering dynamic systems and control students with supplemental remote laboratory experiments and simulation exercises it is concluded that remote laboratory approach is both interesting and promising. Students had increased interest due to the international aspects of the RLab. Even though the RLab was found to be interesting and a different approach to expand the scope of experience for the students, it was not surprisingly found to be as beneficial as hands-on electromechanical plant experiments when directly compared.

The visualization is an important aspect of experiments. In order to improve the use of RLab, it is necessary to overcome the difficulties of the camera issues which is very tractable. The students can then have a better perspective of the plant behavior. Another need is to make the Twin Rotor System a more stable SISO when used in this mode so the output results can be more accurate and more likely to match with the software simulation results. This would help avoid confusion that students may have. These two issues played a key role in the RLab application in this pilot study and are resolvable. RLab is proving to be a great tool to use in the classrooms where there is an access to a computer with internet. RLab has the potential to allow students to use wide variety of plants wherever and whenever.

Improvements for the dependencies of the site hosting the remote laboratory are important for future development and implementation of RLab. The host site needs to be transparent particularly for visualization. Newer developments in video access can facilitate this requirement, however institutional security and firewalls continue to pose barriers to

overcome. Not all experiments lend themselves as easily for remote access. As seen with the Twin Rotor of this pilot study, some intervention from the host site may be required. This is also true for many of the ECP experiments and is under consideration as UNF develops host-site capabilities and making newer versions of RLab more robust.

In this pilot study, dissimilar plants were used by the students with the comparisons made for the results inferred. A future pilot study may involve the similar types of plants while a more exacting quantification comparison can be made between remote experimentation vs. the traditional hands-on approach. As UNF continues to add experiments to the ECP suite of electromechanical plants, the suite of remote access experiments is underway. Additionally the RLab concept is being considered for development of remote laboratories in robotics courses and extensions of fabrication in advanced manufacturing courses and remote fabrication laboratories.

ACKNOWLEDGEMENTS

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