AC 2010-224: INTERNATIONAL COLLABORATION IN AN UNDERGRADUATE CONTROL SYSTEMS COURSE

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International Collaboration in an Undergraduate Control Systems Course

Abstract

This paper presents the results of a collaborative group project involving teams of students from the University of Detroit Mercy in the United States and the Federal University of Minas Gerais in Brazil that took place during the summer of 2009. This assignment was given as part of existing undergraduate control systems courses offered at the participating universities. As these are existing courses that are currently required in the respective curricula, students were not required to take an extra course and a range of students were reached. Furthermore, the entire project was performed at a distance employing readily available technologies such that additional costs were not a concern.

Introduction

The effects of globalization on the United States economy are well-documented and have significant implications for the engineers of today and the near future. It has been observed for many years the movement of domestic manufacturing operations overseas in order to leverage available cost advantages. What began as the export of unskilled manufacturing jobs has grown to include service sector jobs like customer support and even computer programmers. This trend continues today with skills unique to engineers being viewed as commodities that can be supplied by people all over the world. By some estimates, one third of all domestic jobs are susceptible to off-shoring[1].

The rapid development of various information technologies have greatly lowered barriers to information for people all over the world and has enabled the export of skilled engineering jobs. This fact is exemplified by statistics on the numbers of engineers being graduated in China and India as compared to the United States. While specific numbers are subject to debate, even conservative estimates show that the number of engineers produced by China and India together double or triple the number produced in the United States[2]. Trends also indicate that this gap will continue to grow. Statistics for 2004-2005 academic year showed that domestic engineering enrollments were down for the second year in a row, and worse, that less than 5 percent of undergraduate degrees were awarded in engineering in 2005 as compared to almost 8 percent in 1985[3]. With greater numbers of foreign engineers available, the export of jobs is then driven by their lower cost. For example, eight young professional engineers can be hired in India for the cost of a single engineer in the United States[4].

The implications of these numbers for the engineering students of today are twofold: (1) students of today face much more international competition for jobs than they have in the past, and (2) as practicing engineers they are much more likely to have to work with engineers from all over the world. In order to prepare our students for this new environment, it is necessary that we educators modify and improve their preparation. It is no longer enough that our students be technically competent, they must excel as leaders, communicators, and innovators. This viewpoint is widely recognized and expressed by a variety of government reports[5,6,7], by ABET accreditation standards, and even in popular literature[8].

This paper presents the results of a collaborative group project involving teams of students from the University of Detroit Mercy (UDM) in the United States and the Federal University of Minas Gerais (UFMG) in Brazil that took place during the summer of 2009. This assignment was given as part of existing undergraduate control systems courses offered at the participating universities. As these are existing courses that are currently required in the respective curricula, students were not required to take an extra course and a range of students were reached. Furthermore, the entire project was performed at a distance employing readily available technologies such that additional costs were not a concern.

The outline of the paper is as follows: first the specific approach to international collaboration taken in this project is compared to alternative techniques found in the literature, the details of the approach taken in the project of this paper are then outlined, next the success of this project is assessed, and finally conclusions and suggestions for future improvements are made.

Alternative Approaches

While there is in general a consensus that there is a need for today's engineering students to develop skills necessary to compete in an increasingly globalized world, questions still remain about how to best meet this need. The specific goals of the project implemented in this paper were to teach students about cultural awareness and to give them experience working and communicating with a team of international collaborators. Techniques to achieve similar goals that have been explored by other educators include foreign language instruction[9], study abroad programs[10,11], international team projects[12,13], and broader degree and certificate programs with a global focus[14,15].

Several barriers exist that hinder the implementation of the above techniques. One such barrier is the large number of technical courses required by most modern engineering curricula. The sheer number of required technical courses leaves little room for electives like foreign language instruction. Since it is rare for an engineer to take the three or four language courses necessary to begin to develop proficiency, many engineering students are unable to study abroad since the vast majority of international universities do not teach their courses in English. The rigidity of the engineering curriculum also hinders participation in study abroad programs since the courses and their sequence often do not align between universities, especially in the case of foreign universities whose curricula differ from those commonly found in the United States. In terms of percentages of students that study abroad, a recent study shows that engineering students rank in the bottom three of all majors, ahead of only agriculture and math and computer science majors[16]. The option of participating in international team projects is more achievable in that it requires the alignment of only one or two courses, and because they leverage the fact that students in many other countries already have a working knowledge of English. These courses, however, are often specialized electives and hence only reach a small proportion of the undergraduate population. Furthermore, many of the projects propose that the international teams meet in person in order to facilitate student interaction and to enable projects of sufficient complexity. The expenses for travel in these instances are often prohibitive. The broad degree and certificate programs mentioned above are difficult to implement as they generally require all of the above elements: language instruction, travel abroad, and international collaboration.

One solution to many of the barriers above is to decrease the number of technical courses required of engineering students, or to stretch engineering programs to 5 years. The collaborative project of this paper was implemented within the structure of existing engineering programs and as such did not change the number of required courses or the overall length of the program. Specifically, the project was implemented as part of control systems courses required in the standard engineering curricula of the two respective universities. Furthermore, the project was carried out primarily over e-mail to facilitate remote collaboration and did not involve any foreign travel, thereby helping to minimize the necessary costs. A fraction of the U.S. students also received coordinated instruction on globalization and cultural awareness through a 1 credit course meant to prepare them for various issues associated with their future professional lives.

Project Description

The international collaboration of this paper took place as part of a group project implemented among teams of students from the U.S. and Brazil enrolled in undergraduate control system courses. The elements of control system development that are commonly taught in the undergraduate curriculum are how to model a given system, how to analyze the system, and how to design the controls to modify the system's performance to meet some desired specifications. It is often the case that introductory controls courses are very mathematical and provide the students little opportunity to apply the theory. Therefore, aside from the international component, it was also a goal of the project to help the students become better problem solvers and to help them build intuition and practical knowledge about control system design and analysis.

The project was performed by four different teams, each consisting of two to three U.S. students and a single Brazilian student. Two of the teams performed their project on one physical system, while the other two teams performed their project on a second physical system. Both of the systems were physically located at UFMG in Brazil. Due to the small number of Brazilian students, the two Brazilian students working on each of the two different physical systems were allowed to work together, though they communicated with their respective U.S. partners independently. The project involved the students completing the entire control system design process from specification, to modeling, to analysis and design. The students at the respective universities were in charge of different elements of the design process, but were graded on the whole project, even those elements that they did not lead. Grading was performed in this manner in order to encourage the students at the different universities to interact with one another and to learn about the entire design cycle. Additionally, the assignments given to the students at the respective universities contained only details regarding the portion of the project that they were in charge of. This was done in order to force the students at the different universities to communicate effectively in order to produce a successful design.

<u>The Students</u>

The students at UDM were enrolled in an introductory controls systems course (ENGR 3220/4220) that is required of electrical engineering majors, though some mechanical engineering students also take the course as a technical elective. The electrical engineering students are primarily of junior standing while the mechanical engineering students primarily have senior standing. The course emphasizes theory and spends the majority of its time on modeling and analysis tools. Actual control system design techniques are introduced for PID control, but it is not the focus of the course. The students with junior standing also typically enroll concurrently in the 1 credit professional preparation course mentioned previously.

The students at UFMG are upper division students majoring in a control and automation degree. This course is primarily a laboratory course where students gain experience applying the theoretical tools they have learned in prior coursework. The Brazilian students also possess some proficiency in English, though most are not fluent. Specifically, engineering students at UFMG are required to pass an English competency exam to earn entry to the university and are further required to take a year-long English course once enrolled. Most of the students are relatively comfortable reading and writing in English, though speaking poses more difficulty.

Responsibilities and Schedule

As described above, the students at each of the respective universities have different skills and are enrolled in courses with different goals. Additionally, the course at UDM runs from the beginning of May to the middle of August, while the course at UFMG runs from early March to the middle of July. These constraints affected which half of each team was put in charge of each portion of the project and at what point each element of the project was due. At a high level, the students at UDM were primarily in charge of the modeling and analysis for the project with some controller design, while the students at UFMG were in charge of the controller design and all testing and implementation on the physical system.

The timeline of the project began with the groups being assigned in the middle of May. At this point, the U.S. students were required to contact their Brazilian collaborator. This first contact provided an opportunity for the students to get to know one another and to start to gain experience with the communication techniques that would be employed during the semester. By this point, the students enrolled in the professional preparation course had been given some instruction on globalization and cultural awareness. The U.S. students were then required to turn in a reflection on their Brazilian counterparts and the interaction that took place. At the beginning of June the Brazilian students were required to communicate to their U.S. partners information regarding the physical system to be controlled, including information regarding sensors and actuators. Based on this information, the U.S. students then built from first principles mathematical models of their assigned system and the associated control hardware. These models were described in a memo sent to their Brazilian counterpart in the middle of June. At this point, the Brazilian students also sent data to their U.S. partners documenting the uncontrolled operation of the given system. The U.S. students then analyzed this data and compared it to the behavior indicated by their mathematical models to assess the accuracy of their models and to identify various physical parameters. Concurrently, the Brazilian students generated controls specifications based on the goals of each of the systems. The results of this work were then communicated via a second memo to each of the respective sets of partners. At this point, the Brazilian students then performed extensive work on designing and implementing controllers for their given system. The results of this work were communicated back to the U.S. students before the UFMG semester ended in the middle of July, though some of the Brazilian students had to continue working on their project past the end of their semester. The U.S.

students then analyzed the performance of the system with control based on the closed-loop data provided by their partner. The U.S. students then attempted to design their own controllers and compared the resulting performance to the Brazilian designed controllers using simulation. At the end of their respective semesters, the UFMG students were required to write a final report, while the UDM students were required to give a final oral presentation. A summary of the responsibilities and their due dates for the project are given in the following table.

UDM Activity	**UFMG Activity**	**Due Date**
Get to know partners	Get to know partners	May 28th
-	Produce description of system	June 11th
Construct system model	Collect system response data	June 18th
Identify parameters	Generate controls specifications	June 25th
-	Design control and implement	June 31st
-	Produce final report	July 8th
Analyze closed-loop behavior	-	July 15th
Redesign control and simulate	-	July 30th
Give final oral presentation	-	August 6th

Though the students were graded primarily on their final reports/presentations and the formal communication that took place in the form of memos, they also needed to communicate informally to clarify information and to help guide them in between milestones. This communication took place primarily via e-mail and was recorded by each of the teams in a communication log.

<u>The Physical Systems</u>

The two systems employed in this project were complete off-the-shelf units produced for the purposes of controls education. This was done in order that the students could focus on control algorithm design and implementation, rather than on the implementation of the hardware and software needed to enact the control. The students, however, were not given the manuals that accompany these systems because the manuals in general contained much of the information in terms of specifications, models, and controllers that the students were being asked to produce themselves. Through their assignments the students were given only enough information to allow them to perform their prescribed tasks.

One physical system employed in this project was the mass-spring-damper system produced by Education Control Products (ECP) shown in Figure 1. The specific configuration employed by the students included two masses, two springs, and a single damper. Systems of this type can be found in most any undergraduate controls textbook and are straightforward for the students to understand and model. One complication that the students observed in practice was that the linear models that they derived from first principles did not exactly match the actual behavior of the system. Another difficulty that the students faced was that they were required to concurrently affect the position of two different masses employing only a single force input.

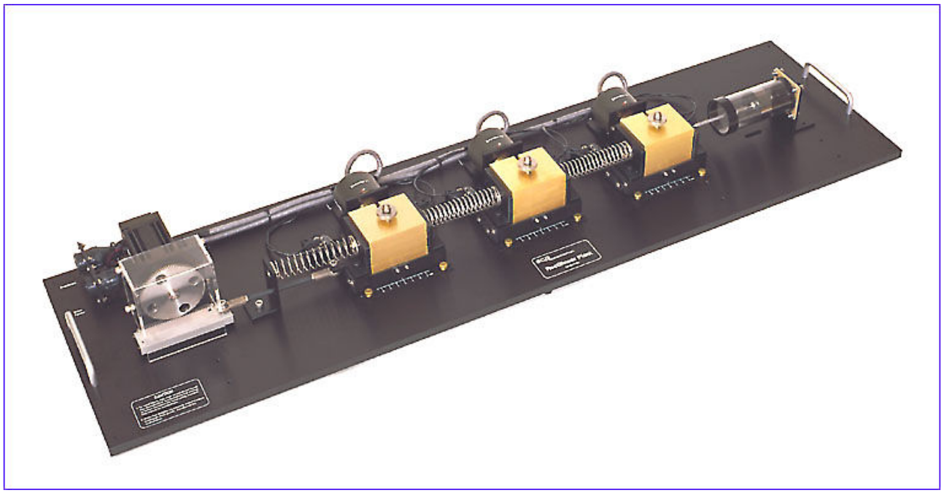

Figure 1 Mass-spring-damper system [http://www.ecpsystems.com/controls_recplant.htm]

The second physical system employed in this project was the twin rotor system produced by Feedback Instruments Limited shown in Figure 2. For the purposes of this project, the twin rotor was constrained to move only in a vertical plane and only one of the two rotors was used for control. The rotary dynamics of this system is relatively straightforward for the students to model, but the dynamics of the thrust produced by the rotor had to be supplied to the students. A difficulty that arises with this model is that the thrust dynamics and the overall rotational dynamics are both nonlinear. Therefore, the students had to generate a linearized model for the system, and as was the case with the mass-spring-damper system, they observed that the modeled behavior and the actual behavior did not match exactly.

Figure 2 Twin rotor system [http://www.fbk.com/product.aspx?pid=33-007]

Grading

The grades of the UDM students were primarily determined on the basis of their technical memos and their final presentation. Specifically, 50% of their grade was determined based on their four technical memos, 40% was from their final presentation, while the remainder was split equally between their reflection on getting to know their Brazilian partner and their communication log. Additionally, each individual's grade was scaled based on an evaluation of their contribution to the project made by their team members.

Evaluations and Observations

The success of this project is based on the observations of the instructors for the courses (the authors of this paper) and the results of surveys supplied to the students at the conclusion of the semester. Furthermore, success is evaluated in terms of the two overarching goals of the project: (1) that the students learn about and gain experience with international collaboration, and (2) that the students learn the technical subject matter of control system design and analysis.

<u>International Collaboration</u>

Overall, the authors of this paper feel that the students learned about and gained a modest amount of experience with international collaboration. Between the four different groups, the communication logs presented at the conclusion of the project indicated that there were on average 16 different e-mails sent between members in the two different countries. One Brazilian group also recorded and posted a video of the closed-loop operation of their system. This amount of communication is significant and provided the students much experience with communicating technical information in a clear and concise manner such that it could be understood by team members from a different culture. Throughout the course of the project there were multiple instances where one half of the team could not perform the work for their milestone because their partner did not send the correct information, or the information was unclear. A comment from one U.S. student on the end-of-project survey was that "At times I was unsure about what to expect from [student's name]. When he did not do the things he should have, I did not know the difference and were left missing a piece of the puzzle." This confusion, however, was often resolved by additional e-mail communication. A problem with both sides of the communication was that the students often did not leave themselves sufficient time to satisfactorily resolve the inevitable confusion before a given milestone due date.

There were also instances where the language barrier presented misunderstandings. One humorous example was when a U.S. group sent their Brazilian partner an e-mail specifying that they did not understand the "second to last paragraph" of the previous memo and the Brazilian student panicked thinking that his U.S. counterparts did not understand those portions of his memo from the second paragraph to the last paragraph! The overall strength of the Brazilians' language skills, however, were quite sufficient for conducting the project. On the end-of-project survey, the U.S. students rated their partners' language skills as being "sufficient to complete" their tasks with an average score of 4.36 out of 5 where 4 corresponded to agree and 5 corresponded to strongly agree. Furthermore, the Brazilian students rated their English skills as being sufficient to complete the project with an average score of 4 out of 5.

The students in general did not necessarily see the experience with technical communication as being as useful as the instructors did. The U.S. students rated the collaborative project as "providing useful practice in technical communication and intercultural interaction" as 2.91 out of 5, where 2 corresponds to disagree and 3 is neutral. One representative comment from a student on the end-of-project survey was, "The international collaboration part interfered with designing a controller. Most of the time was spent writing memos and stating obvious things in them." This sort of attitude is not totally unexpected in that engineering students often do not see the value in learning how to write and communicate and it is something that they do not always enjoy as much as the technical elements of courses. Additionally, some of the U.S. students found it difficult to envision and understand the system since they could not see it in person.

The Brazilian students tended to value the experience with technical communication higher than their U.S. counterparts as represented by their average rating of 4.75 out of 5. This is perhaps because they valued the practice they gained in communicating in a different language. One comment to this effect was, "I did like to be in contact with people from another culture. I enjoyed communicating in other language too. This kind of opportunity is rare." The Brazilian students, however, would have liked the two halves of the project to be more closely interrelated as indicated by the following comment from one student, "Despite the exchange of emails with the American partners, our work was very much independent from theirs."

A disappointing aspect of the collaboration was that the international communication was performed almost entirely via e-mail. The authors feel that the students would have gotten a better sense of their international partners if the communication would have also included the use of internet chat, or speaking directly using software such as Skype. It is understandable that the students would choose e-mail since it is convenient and comfortable and there was no additional incentive given to use other methods of communication. This is especially true for the Brazilians since English is not their native language. Many of the Brazilians relied on the vocabulary and wording of their assignment, which was given in English, to help them write their memos and e-mails. Since there are a variety of levels of language proficiency amongst the Brazilian students, it would have been helpful if the Brazilian portion of each team consisted of more than a single student. This way the communication could have taken place between teams such that the more proficient team members could have bore a larger portion of the responsibility in any given conversation.

The U.S. students that received instruction on Globalization and Cultural Awareness placed a range of values on the instruction. The U.S. students rated the ability of the presentation on Globalization to motivate the usefulness of the project as 3 out of 5. The benefit to the outcome of the project of the presentation on Cultural Awareness was rated only slightly higher at 3.14 out of 5. However, the students felt that the presentation on Cultural Awareness would be useful in their future career as indicated by their average rating of 4.57 out 5.

<u>Technical Subject Matter</u>

The authors in general feel that the students were even more successful in their learning of the technical subject matter than they were in learning about inter-cultural collaboration. The students learned many valuable lessons about practical issues with control system design that are not typically encountered in textbook problems. One example was that the students gained an understanding of the inherent nonlinearity of real world systems, like the limitations of a linear viscous friction model. Other examples included how real systems may have higher order dynamics and how simulation software (Simulink) can produce erroneous results due to numerical error. These types of lessons would not have been learned, by the UDM students in particular, if not for the addition of this project.

Most students had something positive to say about the technical learning that took place during the course of the project. An example comment was, "I liked the exposure to real world solutions. I was also able to gain a better understanding of the material by learning from my many, many mistakes." Furthermore, the students gave an average rating of 3.86 out of 5 for the statement that the collaborative project "enhanced my learning of the technical material of the course." The scores were very similar between the U.S. and Brazilian students for this statement.

The same issues that provided such valuable learning experiences for the students were also a source of great frustration. Many students made comments on their survey about wasting time with work that ended up being incorrect or a dead end. For example, one student stated that one of the things that they did not like about the project was "The amount of work/time spent on things that we didn't end up needing/were ultimately wrong." Students also felt like the mistakes early in the project caused problems throughout the course of the semester. One comment with respect to this issue was, "The project at times was, at times, very frustrating. The mistakes that I made followed me the entire semester and seemed to snowball."

Some reasons for the frustration of the students were that the project was open-ended and hence the instructors did not necessarily know at a glance whether or not the work performed by the students was correct. It was the first time that the instructors had worked with these physical systems. Furthermore, the form of the model presented in the manual for the twin rotor system was ultimately flawed and led the students to devalue the theoretical work they did since it did not agree very well with the actual data they observed.

<u>General Comments</u>

Another complaint from some students was that the project required too much time. The UDM students slightly disagreed with the statement that the "amount of work required for the collaborative project was reasonable in the context of the overall workload for the course" as indicated by their average score of 2.73 out of 5 on the end-of-project survey. The UFMG students were less critical with an average rating of 4 out of 5. The difference between the students may relate to the structures of the respective courses.

The way that the project was fit into the UDM course was to reduce the number of homework problems. For example, instead of the students performing two more modeling problems from the textbook, they instead derived the model for their physical system. It is likely that the project did require of most students more time than would have been required if the project had not been assigned. The tasks required of the project were generally more involved than the textbook problems. Additionally, much more time had to be spent checking work and attempting to reason about whether or not the work was correct, which is a useful exercise, but is difficult in the presence of real-world complications. Additionally, some students had to perform more work in order to carry the slack for weaker team members.

In terms of the actual subject matter that was covered in the UDM course, the project did not have too much of an effect. A couple of topics that were required of the project could have possibly been swapped for other topics. For example, linearization and state space modeling were included in the UDM course, but are not central to the learning outcomes. It does, however, seem that the UDM students gained more practice with topics early in the semester like modeling and time domain analysis, than they did with later topics like frequency domain analysis and controller design because of the requirements and timing of the project.

The UFMG course had in the past also included a final project, so the addition of the international collaboration did not significantly affect the structure of that course. It is likely, however, that the increased emphasis on communication meant that the Brazilian students spent less time on the design and test of their controllers.

Despite all of the difficulties, both the students and instructors felt that the project was successful and made a useful contribution to the course. The UDM students rated the statement that "the collaborative project was a useful part of the course" as a 3.64 out of 5, while the UFMG students gave the same statement a rating of 4 out of 5.

Conclusions and Future Work

This paper presented the results of a collaborative project that took place between students at the University of Detroit Mercy in the U.S. and the Federal University of Minas Gerais in Brazil. The purpose of the project was to provide students with skills and experience in inter-cultural collaboration. One advantage of the approach taken in this endeavor was that the project was included in courses required of typical engineering majors at the two respective universities. Additionally, since the collaboration was performed at a distance employing e-mail, the financial costs were minimal.

Overall, both the students and the instructors found the collaboration to be a success, though there are several ways in which the collaboration could be improved when it is attempted in the future. One way to improve the collaboration would be to get the students to communicate in more ways than just via e-mail. In future course offerings it is likely that enrollment in the Brazilian course will be significantly larger; therefore, each group will include more than one Brazilian student. This will be advantageous because then the responsibility for communication can be spread over more students. Another thing that could encourage the use of multiple modes of communication would be to offer the students extra credit. The instructors consider offering extra credit more reasonable than requiring multiple modes of communication because they are not sure that they can require the Brazilian students to communicate in English since the course is required. Future implementations of this project will likely go more smoothly also because the instructors will be more familiar with the physical systems and the types of difficulties and results to expect. It is also proposed in future offerings that an improved structure for the model of the twin rotor system be employed. Other ways to make the project go more smoothly include to break the assignments into smaller parts to encourage better planning and to give more instruction for the communication so that both sides better understand what to expect from their international collaborators. This further instruction can also decrease the amount of work required by the students for writing their memos if they can better focus their communication. The students can also be encouraged to reuse or refer to figures from their specific assignment in order to decrease the repetition of work. Finally, for the benefit of the UDM students it is proposed that the UFMG students be required to record video of their physical system in operation in order to help the UDM students better understand their system and to get them more excited about the project.

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