AC 2007-1600: DEVELOPMENT OF AN UNDERGRADUATE INTELLIGENT SYSTEMS LABORATORY AND CLASS

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Development of an Undergraduate Intelligent Systems Laboratory and Class

Introduction:

Ohio Northern University (ONU), a small, private, undergraduate university has received NSF funding to adapt and implement an Intelligent Systems Course currently in-place at the University of Notre Dame. The original course enrolls both undergraduate and graduate students. However, at this school, the course was implemented last year as a senior-level elective, enrolling students from both Mechanical Engineering and Electrical Engineering. Adaptation of the course focused on changes to accommodate the fact that students were only undergraduates from a variety of majors, and to accommodate a quarter-based academic calendar rather than semesters.

Students attended a weekly laboratory session which involved using hardware and/or software to implement, and discover the limitations of, the various algorithms discussed in class. One such laboratory required students to work with students at the other institution in order to complete the project. Students were assigned to teams including students from both universities. Each team was required to create an algorithm which would control the temperature of a system at the remote site. To further add to the complexity of this task, the hardware was different at each site.

The course topics included non-linear systems, chaotic systems, expert systems, fuzzy logic, neural networks, and genetic algorithms. All laboratory exercises were computer-based, group exercises. Students had to implement intelligent algorithms to control a variety of systems, including a fluid-mixing temperature control system, and a 3-DOF helicopter system from Quanser.

The course was taught with a focus on active learning techniques and student involvement, rather than the more traditional lecture-only method. Student and instructor reactions to this are included in the paper.

Detailed descriptions of the course, laboratory, and the remote laboratory exercise will be included. Also included will be pre- and post- surveys of students' confidence in their ability to control systems, as well as direct assessment of student capabilities.

Background

Engineers are increasingly required to have the ability to work with complex, integrated systems, which often include mechanical, thermal, and electrical components, as well as microprocessor control. As is the case in many undergraduate engineering programs, students at ONU previously had very limited exposure to such systems. The development of the new Intelligent Systems course and laboratory was focused on such systems. The course was intended to be open to both Mechanical Engineering and Electrical Engineering students. Because the cost of developing such a laboratory could be prohibitive, it was decided to propose to the National Science Foundation Course, Curriculum, and Laboratory Improvement (CCLI) program to adapt and implement a course and laboratory on Intelligent Systems.

Such a proposal was clearly in keeping with the strategic plan of the College of Engineering at ONU[1]. Particular strategic plan actions that related to this proposal include:

- "Regularly reassess the curriculum, and make comparisons to curriculums of other institutions. Changes to the ONU curriculum may be made to keep pace with industry and other leading-edge institutions.
- The integration of engineering courses with mathematics, physics, and chemistry courses as well as integration within each department should be accomplished to provide the best learning environment possible for the students.
- A balance of 'hands-on' applications and theoretical expertise and understanding should be established to best prepare the students for future professional endeavors.
- Additional upper-level elective courses should be established to provide a greater depth of coverage than currently exists. The faculty will research traditional and newly developed techniques and subject areas required by industry. In so doing, the topics and techniques necessary to best prepare students for industry will be brought into the classroom.
- The faculty will investigate new and innovative teaching methods and materials. They will explore techniques and equipment being used by other institutions to enhance the educational environment, and those deemed useful will be placed into use in the College of Engineering.
- Investigate and assess the use of distance learning techniques as well as other forms of education."

While a variety of definitions have been given for intelligent systems, the IEEE Computer Society (which publishes a journal with the title Intelligent Systems) discusses "systems that perceive, reason, learn, and act intelligently[2]." Such systems are usually complex, nonlinear, and involve a variety of disciplines (since simpler, linear systems can be successful using traditional techniques). The particular focus of this course will be the control of nonlinear systems through 'intelligent' algorithms.

Course Description:

Nine students, including seven mechanical engineering students and two electrical engineering students, were enrolled in the new course at ONU. The course met for three fifty-minute lectures and a one-hundred-ten minute laboratory each week. Students had twenty-four-hour swipe-lock access to the laboratory. The ten-week course followed roughly the following schedule:

- Week 1:
    - Lecture: Introduction, limitations of linear assumption
    - Lab: Demonstration of inverted pendulum and saturated amplifier to demonstrate the effects of nonlinearities

- Week 2:
  - Lecture: Chaos, game of life, nonlinearity
  - Lab: Chaos, numerical integration in chaotic systems
- Week 3:
  - Lecture: Introduction to neural networks
  - Lab: Implement neural networks in Matlab with toolbox
- Week 4:
  - Lecture: Student presentations on neural network applications, noise, various methods, training, limitations
  - Lab: Implement neural network in Excel or C++ and compare with Matlab
- Week 5:
  - Lecture: Expert systems, intro to genetic algorithms
  - Lab: Genetic algorithms implementation in Matlab with template
- Week 6:
  - Lecture: Student presentations on genetic algorithm applications, further genetic algorithms, Mid-term exam
  - Lab: Genetic algorithms implementation from scratch in Excel or C++
- Week 7:
  - Lecture: Fuzzy Logic
  - Lab: Temperature control of a 'hot box'.
- Week 8:
  - Lecture: Fuzzy Logic
  - Lab: Remote control of a 'hot box'
- Week 9:
  - Lecture: Comparisons, limitations, applications, current research
  - Lab: 2-week lab, control of fluid mixing laboratory or 3-DOF helicopter
- Week 10:
  - Lecture: Review
  - Lab: Complete week 9 task

It should be noted at this point that most lectures were not traditional, 'Sage on the Stage' lectures. The instructor tried to limit any lecture times to 20 to 25 minutes. Then there would be a time of class discussion, comments, or a class activity. Frequent surveys were given to the students for formative assessment throughout the course. Some courses were devoted to student presentations on the new topic.

Laboratories:

The laboratories consisted of a mix of simulation and hands-on experiences. A full description of these can be obtained from the author upon request. A brief discussion of the hands-on laboratories (with hardware) is included here:

1) Inverted Pendulum system: The hardware for this experiment is from Quanser systems, Control Challenges: Linear: Inverted Pendulum[3]. If traditional undergraduate-level control theory is applied complete with linearization, a highly

unstable system results. This was demonstrated, along with a PID controller which also fails, and an LQR controller which can work with proper initial conditions. After the demonstration, classroom discussion ensued about why these behaviors were observed.

2) Saturated amplifier experiment: In a speed-control system using a DC motor, traditional undergraduate-level control theory would ignore the saturation of the motor and indicate that a proportional controller with very high gain would give the best possible performance. Although the students in this class had been exposed to this limitation in a laboratory associated with their controls course, this was further demonstrated in the laboratory and discussed in class.
3) 'Hot Box.' This system consists of a plexiglass box with a high-temperature halogen light bulb, a thermistor, and a fan. Students were allowed to select their preferred algorithm in order to control this system using one or both of the inputs (the fan and/or the light).
4) 'Remote Hot Box.' In conjunction with Notre Dame, this experiment consisted of using the internet to control a system similar to that in the previous experiment. Students had to work with students in the course at the other university in order to obtain the needed information for the laboratory to be successful. Because of the introduction of the internet into the control loop, the effect of indeterminacy in a controller was discussed.
5) Fluid mixing. Two tanks of water, one at room temperature and one at high temperature (but below boiling) were provided, along with pumps on each. A controller was designed to control two pumps in order to maintain a desired fluid temperature in the mixing tank. This was done using their choice of any of the algorithms discussed in this course.
6) 3-DOF Helicopter. This system was a system from Quanser[4]. By controlling the speed of the two inputs to the system (two rotors), students created two 'behaviors': hovering and circling. This was done using their choice of any of the algorithms discussed in this course.

Student Presentations:

Students at ONU have extensive experience giving technical presentations. These presentations are typically ten to fifteen minutes in length and involve the use of PowerPoint, and are often done in groups. However, the students have little experience with 'elevator-pitch' types of presentations (presentations which attempt to 'pitch' an idea and are typically very short and relatively unrehearsed). As such, students were asked to give very brief (less than five minutes) presentations on an application of the current topic that they found interesting. Assessment is found below.

Assessment:

A variety of assessment tools were used in this course. These included pre- and post-surveys of students' confidence in their ability to control systems, formative assessment using student surveys, a post-survey about the course, and direct measure of students' ability to meet course outcomes.

Four times during the quarter a formative assessment was completed. These involved two to four questions, typically asking for major topics, what had been learned in a laboratory, hours spent on the labs, and suggestions for improvement. Students consistently identified the major topics correctly, and had few suggestions for improvement.

Appendix 1 shows the survey used at the end of the course. A 4-point scale was used to discourage neutral responses. The first twelve questions were also given to the entire class of mechanical and electrical engineers at the end of their Controls System courses (before the Intelligent Systems course) to serve as a pre-survey. The bold (first) numbers in the blanks represent the average value of the student response. Note that the average response was consistently at the level of 'agree' (3) or higher. The median response to all questions was a 3 (agree) or 4 (strongly agree). This indicates that students left the course with confidence in these categories. The second number in each blank is the pre-survey result for the same item. Note there are striking differences in most of the categories. Note that the number of responses is also quite different, with N=9 for the post-survey and N=46 for the pre-survey. (Because of this, the data should not be considered statistically significant.) It is interesting to note that the response to question 11 ("I can improve the performance of a control system") became lower on the post-survey. The author speculates that this is due to the complexity of the systems utilized in the course, which made students realize that the theory they learned in their initial controls courses had significant limitations.

In response to the open-ended questions, several comments stated that the worst thing was the lack of a textbook. Since this is a relatively new field, the course simply consisted of class notes and students were given web and library resources for additional reference. This is a very different model than students at ONU are accustomed to. A textbook will be considered for the next iteration of the course. Sample student responses to 'what was the worst thing about this course' included:

- *Not having supplemental materials with lectures.*
- *The labs seemed to be loaded down on us at the end of the quarter.*
- *Not having a very cooperative lab group.*
- *I would have liked to have a textbook, rather than relying on my sloppy notes.*

In response to question 2, some students felt that they would have benefited from doing labs individually. Student responses to the next two questions indicated that they found the 5-minute presentations interesting, and felt that it helped their presentation skills. Students did comment that the more challenging laboratory exercises were mostly at the end of the course, but unanimously responded that the laboratory exercises did help reinforce the class material. Most students felt that all of their courses should include some type of formative assessment.

Student responses to the last two questions are included here verbatim:

What did you like best about this course?

- *The material (NN, GA, fuzzy) was interesting.*
- *The interesting labs especially the hot box lab.*
- *Designing our own program from scratch and seeing it work.*
- *I got to learn about new concepts that I otherwise would have no idea exist.*
- *Fuzzy logic/ take home tests*
- *The labs, I learned a lot with them.*
- *The labs were interesting and learning new methods to control system performance*
- *The new technology and ways of thinking interested me.*
- *The lab really helped me learn the material*

Would you recommend this course to another student? Why or why not?

- *Yes.*
- *Yes, because it's a great course to learn about new technologies that aren't taught in any other classes*
- *Yes because it provides a clear understanding of more modern tools.*
- *I would tell people that: "You learn about new things and different approaches to solve control problems, some of which are really cool, but the workload in comparison to PLC's seems like it was much more."*
- *Yes, I learned so much and it was interesting content*
- *Yes, because the subject matter is very interesting. It's important for engineers to be exposed to this.*
- *Yes, it was interesting and offers a new outlook on methods and approaches*
- *Yes, it gives a more broad approach to solving engineering problems. Optimization especially is a large part of engineering.*
- *Yes, you learn a lot of useful stuff and it is fun too.*

In addition to survey-based assessment methods, the standard continuous improvement process at ONU requires direct measures of student achievement. The course outcomes state that upon completion of the course, students will be able to:

1. model complex systems;
2. choose and implement an appropriate algorithm to control complex, multi-disciplinary systems;
3. understand how to implement and test such systems;
4. communicate effectively about their work with such systems; and,
5. analyze and suggest improvements on the performance of such systems.

The assessment method used by the Mechanical Engineering department consists of a faculty course assessment report (FCAR). This is modeled after the format described in Estell[5]. Direct measures (either from a test, laboratory, or homework) of each course outcome are used. The student performance for each assignment is divided into four categories: Excellent, Acceptable, Minimal, and Unacceptable. The number of students in each category creates a vector referred to as the EAMU vector.

For this course, Excellent is scoring an A, Acceptable is from A- to B-, Minimal is from C+ to C-, and Unsatisfactory is anything below a C-. The following assessment material is taken from the FCAR for the course:

CO-1: Model complex systems.
- Lab 2, use Matlab to model a forced pendulum. EAMU vector: (4,4,1,0)

CO-2: Choose and implement an appropriate algorithm to control complex, multi-disciplinary systems.
- Final Exam, in-class portion, choose algorithm. EAMU vector: (6,3,0,0)
- Final laboratory, choose an algorithm to control a fluid-mixing problem or a 3-DOF helicopter. EAMU Vector: (9,0,0,0)

CO-3: Understand how to implement and test such systems.
- Final laboratory, choose an algorithm to control a fluid-mixing problem or a 3DOF helicopter. EAMU Vector: (9,0,0,0)
- Remote Hot-Box control, working with student at Notre Dame. EAMU vector: (9,0,0,0)

CO-4: Communicate effectively about their work with such systems.
- First 5-minute presentation of an intelligent system. EAMU vector: (3,4,2,0)
- Second 5-minute presentation of an intelligent system. EAMU vector: (4,4,1,0)
- Laboratory 4 report. EAMU vector: (6,3,0,0)

CO-5: Analyze and suggest improvements on the performance of such systems.
- Lab 5, Genetic Algorithms, students asked to vary parameters to improve system. EAMU vector: (0,9,0,0)

Note that there were no students who scored unacceptable in any assessment measure. The combination of this assessment with the student responses and comments on the course seem to indicate that the course was successful.

Conclusions:

There are several things worth noting about this course that can be applicable to other institutions:

1) NSF grants can be used to successfully establish new courses and laboratories that also create relationships between very different kinds of institutions.
2) Graduate-focused courses relating to areas of current research can be adapted to an undergraduate audience.

3) Undergraduate students enjoy the topic of Intelligent Systems and are more than capable of developing working algorithms to control complex, multidisciplinary systems.
4) Remote laboratory experiments, while requiring significant setup work and overhead, can provide good learning experiences to students by allowing them to:
    a. Work with students at other institutions using only the internet to communicate;
    b. Characterize and control systems they cannot see;
    c. Have access to equipment they may not have access to at their home institution.
5) Giving students the opportunity to implement algorithms in the laboratory is helpful in their learning of such algorithms.

The authors would be glad to work with others who are interested in developing such a course, laboratory, or additional remote experiments. All course materials are available upon request.

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[2] http://www.computer.org/portal/site/intelligent/ : About IS.
[3] http://www.quanser.com, Control Challenges: Linear: Inverted Pendulum.
[4] http://www.quanser.com, Control Challenges: Specialty, Aerospace: 3 DOF Helicopter
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APPENDIX I: Post-Survey

Spring Quarter, 2005-06
ME 449
Systems Evaluation

Answer the following questions using the scale:

4 – Strongly Agree 3 – Agree 2 – Disagree 1 – Strongly Disagree

3.44/*3.11* 1) I can explain the difference between linear and non-linear systems, and how that difference affects control.

3.11/*2.70* 2) I can use modeling and control systems theory to control nonlinear systems.

3.11/*2.33* 3) I can control electro-mechanical systems such as thermal or fluid systems.

3.00/*2.53* 4) I can control a system without having, or finding, a model of the system.

3.22/*3.22* 5) I can control a system using PID control.

3.22/*1.50* 6) I can control a system using a Neural Network.

3.56/*1.43* 7) I can control a system using Fuzzy Logic.

3.00/*1.46* 8) I can control a system using Genetic Algorithms.

3.56/*2.92* 9) I can explain how I have controlled a system to other students in a presentation.

3.44/*3.03* 10) I can explain how I have controlled a system to other students in a paper.

3.00/*3.30* 11) I can improve the performance of a control system.

3.78/*3.48* 12) I can work with other students to learn new concepts.

3.44 13) I understand Neural Networks.

3.56 14) I understand Fuzzy Logic.

3.33 15) I understand Genetic Algorithms.

Please take the time to answer the following questions. Your input will be used to modify next year's course:

1. What was the worst thing about this course?

2. Would it be better to have the initial labs done individually?

3. Did you find the 5-minute presentations interesting to listen to?

4. Do you feel having to give the five-minute presentations was helpful to you? Why or why not?

5. Should this class include a textbook?

6. Should the labs have been arranged differently?

7. Did the labs help you understand concepts from the course?

8. Should other courses include weekly feedback surveys as we did in this course for several weeks?

9. What did you like best about this course?

10. Would you recommend this course to another student? Why or why not?