AC 2009-743: MERI: MULTIDISCIPLINARY EDUCATIONAL ROBOTICS INITIATIVE

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MERI: Multidisciplinary Educational Robotics Initiative

Abstract

This paper will describe the implementation of an innovative multidisciplinary robotics certificate program at a small teaching institution in the Midwestern United States. The Multidisciplinary Educational Robotics Initiative (MERI) is a product of a collaborative effort between faculty in Computer Science and Software Engineering (CSSE), Electrical and Computer Engineering (ECE), and Mechanical Engineering (ME). At this institution, a certificate is defined as a minor across multiple disciplines, e.g. CSSE, ECE, and ME. This is a groundbreaking program with the certificate curriculum approved in fall 2008. This paper will present the motivation for the certificate program, expected outcomes, details of the program and curriculum, select courses in the program, first graduates of the program, assessment and future work.

Why a Robotics Program?

A robotics certificate or degree program is an increasingly relevant program for undergraduate engineering institutions for a number of reasons, including recruitment, multidisciplinary teamwork, and industry demand.

Recruitment

The multidisciplinary nature of robotics presents an excellent opportunity to attract students with diverse interests to our institution while fostering multidisciplinary teamwork and illustrating connections between engineering and computing. Robotics has recently become a major attraction to science and technology, due in part to the success of the FIRST (For Interest and Recognition of Science and Technology) Robotics Program[1], BotBall[2], and other such competitions. This institution's Admissions department reports that prospective students often express a desire to participate in robotics research and take robotics-related courses at the college level. Therefore, the implementation of the multidisciplinary robotics certificate will help with recruitment efforts[3]. In addition, faculty and students enrolled in the certificate program will participate in K-12 outreach such as mentoring middle school and high school robotics programs. Students in the program will also demonstrate their robotics projects to tour groups, increasing visibility and attracting students to our institution. In fact, the final project robotics competition for one of the early courses in the robotics curriculum has already been featured on the campus web site and in the local newspaper. Additionally, faculty with an expertise in robotics will be attracted to a school with a visible, established robotics education program and research.

Multidisciplinary Teamwork

Robots are mechanical systems with electrical controls and sensors, given intelligence through software. As such, it would be ideal for teams with a collective expertise in these areas to implement and use these systems. The multidisciplinary nature of robotics makes it ideal for teaching collaborative teamwork and the integration of different fields of science, computing, and engineering. Students who participate in these projects will graduate with a deeper and

broader exposure to their chosen major than students who work solely within their single discipline. Students in this program will also have a more realistic perspective of the type of team demographic they will encounter when they enter the workforce. Typically, in industry there will not be teams of solely mechanical engineers or computer scientists working on a project. Students in the MERI program will be exposed to real world application of theory such as controls, kinematics, or software development presented in their respective curriculums. Thus, robotics senior design projects are an ideal mechanism to naturally bring together students across departmental boundaries to work together to solve difficult problems[4-11].

Industry Demand

Some of the institution's industry partners have expressed a desire to hire employees who understand the connections between different fields and can work with peers of other disciplines. These partners need employees with deep exposure in their chosen discipline but also broad exposure to related disciplines. Industry requires scientists and engineers who are specialists in their fields, who know enough about another field to apply their knowledge and can work as part of a team of people from multiple disciplines. Students in the certificate program will learn invaluable skills with the multidisciplinary teamwork and the application of their conceptual content knowledge to various tasks even if their career path does not include robotics. Although some technical degrees and graduate programs in robotics engineering exist, there are very few cross disciplinary programs at the undergraduate level. The U.S. Department of Labor has identified several key growth areas based upon discipline. Although this list does not specifically identify robotics, some of the robotics-related industries with growth potential until 2016 are: plastics, pharmaceutical, aerospace, medical equipment, transportation, navigational, measuring, electromedical, control instruments, manufacturing, and computer systems design[12].

In summary, robotics provides an excellent opportunity to attract a diverse body of students, while fostering multidisciplinary teamwork and thus preparing students for a variety of industries. Despite the obvious value of robotics to undergraduate education, many institutions have little more than a few robotics courses in one specific department. Few undergraduate institutions have a formal multidisciplinary robotics undergraduate program. Some notable programs include Worcester Polytechnic Institute's newly-created major[13], Carnegie Mellon's minor[14], Princeton's certificate[15], and Tufts' Robotics Academy[16]. Other institutions have an active robotics presence, but do not have formal programs. Harvey Mudd College has senior design projects in Computer Science and sponsored the 2007 AAAI Spring Symposium[17, 18]. Southern Illinois University at Edwardsville has multidisciplinary robotics courses and projects[19]. Spelman College is an undergraduate, liberal arts college with Computer Science students who compete on the graduate level at the Robocup competition with the Sony Aibo[20]. The Milwaukee School of Engineering has a robotics senior design project team in Mechanical and Electrical Engineering[21].

Robotics Certificate Outcomes

The authors have developed a formal Robotics Certificate program with the following projected outcomes:

1. An increased number of students who enroll at our institution based upon expressed interest in the robotics certificate program over three years.

2. More interactions between students of various majors, as they take common courses such as Mechatronics, Mobile Robotics, and our new freshman robotics programming course. They will achieve both depth and breadth in robotics, serving as domain experts for their major, and routinely applying this expertise to other disciplines. This will culminate in required, multidisciplinary senior design projects. We expect a minimum of five multidisciplinary senior design projects with a robotics focus over three years.

3. Increased marketability of graduates earning the certificate. Clearly this should be the case for students entering the robotics field, but we believe that the multidisciplinary experience will transfer to increased marketability in other fields, because it is invaluable for entry level employees in many industries.

4. A minimum of ten students on track to graduate with a robotics certificate by the end of the third year.

5. A new, integrated robotics programming course with a minimum of 100 students from multiple disciplines enrolled over three years.

These outcomes are short-term, related to student activity in earning the certificate. They are intentionally outcomes we believe we can measure. The robotics certificate also will aid participating students achieving the longer term *objectives* already expressed in their majors, objectives in the timeframe of 3 – 5 years after graduation. For example, the certificate program builds students' ability to do independent learning, and builds in a different way their communication skills. Both of these are objectives of the major programs in which they are involved.

Robotics Certificate Details

At our institution, a certificate is a multidisciplinary minor, consisting of courses from four departments: Computer Science and Software Engineering (CSSE), Electrical and Computer Engineering (ECE), Mechanical Engineering (ME), and Physics and Optical Engineering (PHOE). The goal of the robotics certificate program is to have students major in a single area to gain depth while also gaining breadth in a second area. To achieve these goals, each student must first major in a robotics-related discipline: Mechanical Engineering (ME), Electrical Engineering (EE), Computer Engineering (CPE), Computer Science (CS), or Software Engineering (SE). He or she must then complete three other requirements:

1. A robotics certificate track
2. A robotics elective course
3. A multidisciplinary robotics senior design project.

Robotics Certificate Tracks

We have developed nine certificate tracks, shown in Table 1, that correspond to combinations of disciplines and skill sets deemed valuable by our industry partners. Students select a track corresponding to their chosen major and secondary interest, and complete the courses in it.

Table 1: Robotics Certificate Tracks. Courses are colored by department: yellow (CSSE), pink (ECE), blue (ME), and green (PH).

#	Track	1	2	3	4	5	6	7
1	CSSE with Controls	Intro to Robotics Prog.	Mechatronics	DC Circuits and AC Circuits		Linear Control Systems	Mobile Robotics	Elec
2	CSSE with Hardware			DC Circuits and AC Circuits		Robotics Engineering	Artificial Intelligence	Elec
3	CSSE with Mechanics			Cons. & Acct. Princ.	Mechanical Systems	Kinematics	Robotics Engineering	Elec
4	CPE			Linear Control Systems	Data Structures and Analysis	Statics & Mech. of Materials I	Mobile Robotics	Elec
5	EE with Programming			Object-oriented Software Dev.	Data Structures and Analysis	Robotics Engineering	Mobile Robotics	Elec
6	ECE with Sensors			Optical Systems	Microsensors	Image Proc. or Wireless Sys.	Mobile Robotics	Elec
7	ECE with Mechanics			Conservation & Acct. Princ.	Mechanical Systems	Kinematics	Mobile Robotics	Elec
8	ME with Electronics		Kinematics	Introduction to Logic Design	Electronic Device Modeling	Robotics Engineering	Mobile Robotics	Dig'l. Sys.
9	ME with Programming		Kinematics	Object-oriented Software Dev.	Data Structures and Analysis	Robotics Engineering	Mobile Robotics	Elec

In Tracks 1 and 2, Computer Scientists and Software Engineers supplement their many required software development courses with mechatronics and electronic circuit analysis. Track 1 allows the student then to specialize in control theory, culminating in the Mobile Robotics course. Track 2 allows a student to receive a more hands-on experience with hardware, culminating in the Robotics Engineering course. Track 3 allows Computer Scientists and Software Engineers to focus on mechanics and kinematics, culminating in the Robotics Engineering course. Track 4 is for Computer Engineering students and gives exposure to control theory, developing software for robotics and statics and mechanics of materials. Electrical Engineering students can take track 5 to explore the development of software, both in general and applied to robotics. Electrical or Computer engineering students can take Track 6 and 7. Track 6 focuses on the theory and design of simple and complex sensors including vision or wireless systems. Track 7 examines the mechanics of the robotic system including kinematics and controls. Mechanical engineers who pursue track 8 will learn more about electronics, digital systems, device modeling, and controls.

In track 9, similar to electrical engineers on track 5, the mechanical engineer learns about software development, data structures and developing algorithms for robot control.

We expect a steady state enrollment of 60-100 students, spanning all of the tracks, but primarily within a few. Thus far, students have enrolled in seven of the nine tracks, and the most popular ones are tracks 4, 6, and 9. We are working on a software tool to automatically track students' progress in the curriculum using data from our school's registration system. Table 3 below lists our current enrollments.

Robotics Elective Courses

Students will supplement their expertise in a chosen track with a robotics-related elective course from Table 2. They may choose any course that is not already required for their major or their track. Students can use this course either to gain depth in one area, particularly by taking one of the graduate-level courses, or to obtain more breadth.

Table 2: Robotics Electives

Computer Science	Electrical and Computer Engineering
Artificial Intelligence	Linear Controls
Computer Vision	Signals and Systems
Image Recognition	Wireless Systems
Swarm Intelligence	Mobile Robotics
Teamwork and Robotics	Discrete-time Control Systems (grad)
	Modern Control Systems (grad)
Mechanical Engineering	**Physics and Optical Engineering**
Kinematics of Machinery	Microsensors
Control Systems	Image Processing
Robotics Engineering	Advanced Image Processing (graduate level)
Advanced Control Sys (grad)	
Advanced Kinematics (grad)	

Selected Required Courses

<u>Collaboration</u>

The principal investigators for the MERI program teach four of the courses that are integral to most of the tracks of the curriculum: Introduction to Robotics Programming, Mechatronics, Robotics Engineering and Introduction to Mobile Robotics. In an effort to insure adequate content coverage of the core topics of the curriculum, the PIs have team taught some of these courses, discussed the syllabi for the courses, and sat in on each other's sections. In the future, this collaboration will continue in order to refine the curriculum and course projects to be as multidisciplinary as possible. From a high level perspective, these courses cover the overarching areas in robotics theory including software, hardware, controls and design. The Introduction to Robotics Programming course teaches the basics of software development on an iCreate robot (software). The Mechatronics course teaches the application of microprocessors and

microcontrollers and digital electronics to design embedded control systems (hardware).   The Robotics Engineering course focuses on the design of a robot with topics such as kinematics, control, operation and sensing (design). Finally, the Introduction to Mobile Robotics course teaches concepts in feedback control and behavior-based robotics (controls).

CSSE120R – Introduction to Software Development (Robotics Programming)

The first required course for the certificate is Introduction to Robotics Programming (CSSE120R), a new variant on Introduction to Software Development (CSSE120). Both versions are taught using the Python and C programming languages. In CSSE120R, students learn programming concepts typical of a first course in computing, except many of their assignments include programming iCreate robots, using both the actuators and sensors. CSSE120R has been offered twice in 2008-2009. Projects have included line following, environment mapping, and tracking of other robots. Thirty-six of the fifty-four students who have taken CSSE120R are already required to take CSSE120 (primarily CSSE and ECE majors), while the other eighteen are not (all ME majors). The number of ME majors was only nine of 127 in 2007-2008, and nine of 102 in the non-robotics sections in 2008-2009. We believe this large influx of students who are taking the course because of interest in robotics has made for better interactions within student teams. Future work includes measuring this change.

We attribute part of the increase in diversity of majors to the faculty involved in the course. While one author from the CSSE department was the professor of record in the course in the Fall term, two others from ECE and ME contributed labs and projects, and lectured on specific units. In the Winter, author from the CSSE and ME department each taught one section of the course.

ME 430 - Mechatronics

Mechatronics is required for all mechanical engineering students and is offered every Fall and Winter. This course has been modified to focus more on microcontroller and microprocessor programming and the design of embedded systems to be more relevant to the robotics curriculum. All robotics students must take this course. It is very multidisciplinary, allowing mechanical engineers the opportunity to develop their C programming skills and allowing software engineers opportunity to learn to interface with hardware.

ME435 – Robotics Engineering

The Robotics Engineering course is being redesigned to be a capstone course and is primarily focused on the MATLAB GUI development, kinematics, communication protocol, and microcontroller needed to develop and program a robotic arm. The course starts from a very low level of development and goes through each component of typical robotic system controlled by a PC Graphical User Interface.

ECE497 – Introduction to Mobile Robotics

The Introduction to Mobile Robotics course will be offered for the second time in Spring, 2009. Nineteen students took this course during its first offering in Spring, 2007 and sixteen have

registered for the 2009 section. This is a project-based course where the students develop basic behaviors for a Traxster robot to prepare for the final project competition. The students use feedback control to correct for odometry error, use sensor feedback such as compass, sonar, infrared, encoders, vision to create several behaviors including obstacle avoidance, wall and line following, navigation, color blob tracking, deliberative, reactive and behavior-based control. These robots are programmed using services from the Microsoft Robotics Studio and Visual Studio.   This course lectures and labs focus on the development of algorithms and application of robot theory including robot components, sensors, locomotion, feedback control, reactive control, behavior-based control, and other key topics in robotics research.

Multidisciplinary Robotics Senior Projects

The goal of the program's senior design projects is to bring together students across departmental boundaries to work together to solve difficult problems in robotics. The PIs planned to formalize this process over the next three years as students transitioned through curriculum. However, the approval of this robotics curriculum in Fall, 2008 was met with such a huge reception that several upperclassmen expressed a desire to earn the certificate. Although exciting, this meant that the PIs had to immediately identify multidisciplinary senior design project opportunities for these students as well as customize their curriculum to meet the requirements. The first graduates of the program are described in the next section.

To postpone the complex issues of coordinating senior design projects with three departments' different sets of requirements; one project had an internal client and the other was primarily in a single discipline. Although neither is the ideal model for a multidisciplinary robotics senior design project, they each meet the needs of these first students in the program. In the future, we anticipate creating a robotics senior design course which will be accepted by all three departments. Known issues in accomplishing this goal are the following:

1. The existing departmental senior design project programs are worth different credit hours and start and end at different times in the student's degree program.

2. The existing programs have different sets of deliverables and grading standards. For example, in mechanical and electrical engineering, the courses are based on a more traditional lifecycle model, with deliverables at fairly standard times in the course sequence. In computer science, an agile lifecycle is expected.

3. In the software engineering, design theory is provided during the senior sequence. In the other programs, the design theory is part of courses leading up to senior design and the senior design course is more of a practicum.

4. The departments provide differing amounts of advising and supervision of the student teams. This variability is related to matters such as the team's contact and relationship with their clients and goal setting.

The three departments are currently meeting to develop positions on these matters, related to the robotics program.

Note that the issue is not quite as simple as allowing students to take a senior design sequence in another department instead of the usual one. We fully expect students in each department to meet their own department's standards for senior design, serving as the robotics team's expert in their field. Thus, there is more impetus for maintaining the usual standards in each of the three fields, insofar as this is possible.

First Graduates

There are currently two graduating seniors on track to receive the robotics certificate. Both were doing robotics projects and research before the program existed, so the additional work required for them to earn a certificate was relatively low. An industry partner proposed a senior design project at the time they expressed an interest; they are currently working on this project while enrolled in Introduction to Mobile Robotics and Robotics Engineering. Both students are pursuing careers in robotics: one is applying to graduate programs in robotics, while the other has been hired to work at a robotics consulting firm upon graduation.

Assessment

The introduction of this program has had an extremely positive reception from both students and employers.

It is too early to assess Outcome 1, increased enrollment at our institution based on robotics interest. However, the head of the ECE Department indicated in informal discussion that he has talked to many prospective students who are very interested in robotics. This will be assessed formally via a survey administered annually to first-year students.

We are making progress on Outcome 2, five multidisciplinary senior design projects with a robotics focus over three years. As discussed above, the three departments are currently planning collaboratively on this.

It is also too early to assess Outcome 3, higher marketability of our graduates, but one of our industry partners is very excited about the program and is actively trying to hire our students for his company.

We are on target to meet Outcome 4, ten students making progress toward the robotics certificate by the end of the third year. Approximately 50 students attended an interest session in Fall, 2008. They each completed a brief survey in which we asked them their level of interest (1 = "just curious", 2 = "interested"; 3 = "I will do this"). Some students have also completed and signed "declaration of intent" forms in which they indicate their chosen track. We currently have fifteen of these. Table 3 shows the number of students who have expressed high interest in the certificate by submitting a form or by indicating an interest level of 3 on the survey.

Table 3: Number of students who have expressed high interest in the Robotics certificate, by year and department.

	ME	ECE	CSSE	Total
Masters	2	0	0	2
Fourth-year	2	0	0	2
Third-year	3	1	0	4
Second-year	6	4	2	12
First-year	9	7	3	19
Total	22	12	5	39

We have also exceeded our expectations for the success of Outcome 5, 100 students enrolled in Robotics Programming over three years. Fifty-four students enrolled in the first year alone, and we have scheduled additional sections for next year, based upon student interest.

Future Work

The first stages in the development of an undergraduate multidisciplinary robotics certificate have proven to be very successful and beneficial to the institution and the student body. In the future, the PIs will seek federal and corporate grants to expand the certificate programming to insure institutionalization and long term sustainability. This funding will be used to develop or revise courses in the curriculum and to develop an integrated robotics research laboratory. This laboratory will be directed by the PIs of the program and provide a means for undergraduate and graduate multidisciplinary research and senior design projects. In addition, the formative and summative assessment will continue and be used to provide feedback on areas for program improvement. An outreach and dissemination component of the program will also be implemented so that the students can participate in university recruitment efforts and to publicize the successes of the program.

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