A MULTIDISCIPLINARY ROBOTICS MINOR

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Abstract

Rose-Hulman Institute of Technology recently created a multidisciplinary robotics minor. In this program, students first gain depth in their discipline, majoring in Computer Science or Electrical, Computer, Mechanical or Software Engineering. They then gain focused expertise in robotics by completing a track of robotics-related courses, including embedded systems and robotics programming. They gain multidisciplinary teamwork skills by working on a robotics senior design project with students from other majors. In this paper, we present details of the curriculum, assessment, student interest, and profiles of our first graduates.

Motivation, Philosophy and Goals

Robotics continues to gain an increasing amount of attention in the undergraduate education community. Successful K-12 programs such as the FIRST (For Interest and Recognition of Science and Technology) Robotics Program [1], First Lego League [2], and BotBall [3] have sparked the interest of many incoming freshmen.

At the other end, our institution's industry partners have expressed a desire to hire employees who not only have depth in their fields, but can understand the connections between different fields and can work with peers of other disciplines. Due to its multidisciplinary nature, robotics affords students an excellent opportunity to contribute their understanding to a project that is both large enough so that they need a team to complete it and, more importantly, broad enough so that the team needs to include representatives of other disciplines.

Robots are mechanical systems with electrical controls and sensors, given intelligence through software (Figure 1). As such, a wide variety of skills are needed to design and build them. At Rose-Hulman, the *Multidisciplinary Robotics Minor* is a collaboration between the Departments of Mechanical Engineering (ME), Electrical and Computer Engineering (ECE), and Computer Science and Software Engineering (CSSE).

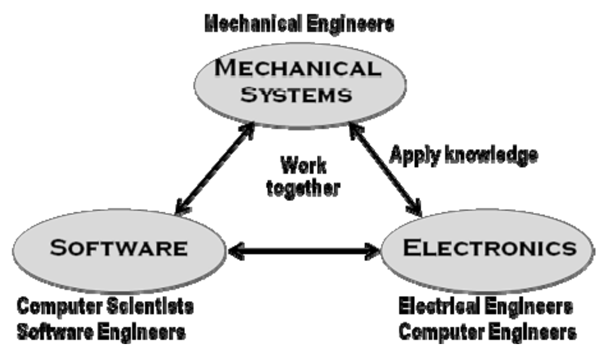

Figure 1: Robotics includes three distinct fields. Our program emphasizes depth first, but obtains breadth through tracks of courses and a multidisciplinary senior design project.

Our industry partners have conveyed to us their need for 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. From this feedback, we have identified three desirable attributes of a robotics program.

Depth in a Robotics-Related Field

Depth in a robotics-related field is important. Like students in any major, robotics students need to master a relevant field, such as computer science, electrical engineering, or mechanical engineering, so they can be a productive member of a team. The authors believe this is preferable to a robotics major because it opens up other career opportunities outside of robotics as well.

Focused Expertise in Robotics

Robotics is such a broad field, that it would be extremely difficult for any student to master all of its branches. However, it is still important for students to have some breadth related to robotics outside of their major. Our industry partners expressed a desire for students to develop skills at the intersection of two robotics-related fields so they can apply their knowledge to another discipline. For example, one of our partners wanted to hire a software engineer who also understood control theory, but couldn't find anyone with that rare combination of skills. A robotics program should require students to take a concentration of robotics-related courses outside of their majors. This concentration should include courses where students learn to program a robot and to develop an embedded system with sensors, control, and actuators. The ability to program a robot is significant because robots use software programs with sensor feedback to make decisions about the environment to accomplish a given task. Thus, programming is the means by which robots gain a level of autonomy and intelligence. Furthermore, if the student can develop an embedded system with sensors, control, and actuators, they obtain a complete view of robotics technology. This system level perspective as opposed to a component level view makes the student better equipped to design and develop a robot to accomplish a given task.

Multidisciplinary Teamwork

The multidisciplinary nature of robotics makes it ideal for teaching collaborative teamwork and the integration of different fields of science, computing, and engineering. Students learn theory, such as controls, kinematics, or software development, and its real-world application in their respective curricula. Robotics is the *synthesis* of these seemingly-disparate fields. Thus, robotics projects are an ideal mechanism to naturally bring together students across departmental boundaries to work together [4-11]. Furthermore, a multidisciplinary robotics *senior design* project would bring together students with enough collective expertise in robotics-related fields to handle the complexity of designing and implementing a robotic system.

Students who do multidisciplinary work enjoy other benefits as well. They will graduate with a deeper and broader understanding of their chosen majors than students who work solely within their single discipline. They will have a more realistic perspective of the type of team demographic they will encounter when they enter the workforce. Finally, multidisciplinary teamwork and the application of conceptual content knowledge in one field to a problem in another field are both valuable skills to anyone, even if his or her career path does not include robotics.

With the goals of depth, focused expertise, and multidisciplinary teamwork in mind, we have identified the following skills that all of our minors should possess upon completion of the program:

1. A deep understanding of his or her field.
2. Focused expertise in another robotics-related field.
3. Ability to develop software for a robot.
4. Ability to develop an embedded system with sensors, control, and actuators.
5. Ability to work with peers from other disciplines.

Related Programs

Despite the benefits of the study of robotics and multidisciplinary work to the development of students' skill sets, many institutions have little more than a few robotics courses in one specific department. However, a few undergraduate institutions do have a formal multidisciplinary undergraduate robotics program. Worcester Polytechnic Institute recently created a major [12]. Carnegie Mellon's minor [13], the University of Maine's minor [14], and Princeton's certificate [15] include coursework from multiple departments, but do not include a multidisciplinary senior design project. Tufts' Robotics Academy [16] has only a multidisciplinary design project, but no coursework. Other institutions have an active robotics presence, but do not have formal programs. Harvey Mudd College has robotics 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]. Lastly, the Milwaukee School of Engineering has robotics senior design project teams in Mechanical and Electrical Engineering [21].

Details of the Robotics Minor

The requirements of our robotics minor ensure that each of our students acquires the desired skill set (see Table 1).

Suitable Majors

To obtain a robotics minor, a student starts by majoring in a robotics-related discipline: Mechanical Engineering (ME), Electrical Engineering (EE), Computer Engineering (CPE), Computer Science (CS), or Software Engineering (SE). Each of these majors provides depth in one of the three robotics fields shown in Figure 1.

Table 1: Mapping of skill sets to courses.

Skill	**How Obtained**
Depth	Major
Expertise	Track
Programming	Required courses in track
Embedded systems	Required course: ME430
Multidisciplinary teamwork	Senior design project

Robotics Tracks

Focused expertise in robotics is obtained by completing a *track* of seven robotics-related courses. These courses span four departments: Computer Science and Software Engineering (CSSE), Electrical and Computer Engineering (ECE), Mechanical Engineering (ME), and Physics and Optical Engineering (PHOE).

All students take a course in robotics programming and a course in Mechatronics. Beyond that, each track is designed to provide a concentration of courses in a second area outside their major.

The nine different tracks are shown in Table 2. These tracks correspond to combinations of disciplines and skill sets deemed valuable by industry partners. Students select a track corresponding to their chosen major and secondary interest.

In tracks 1 and 2, CS and SE majors supplement their required software development courses with mechatronics and electronic circuit analysis. Track 1 then allows a student to specialize in control theory, culminating in the Mobile Robotics course, while track 2 allows a student to receive hands-on experience with hardware. Track 3 allows CS and SE majors to focus on mechanics and kinematics.

Table 2: Robotics Certificate Tracks.

#	Track	1	2	3	4	5	6	7
1	CSSE with Controls	Intro to Robotics Prog.	Mechatronics	DC Circuits and AC Circuits		Dynamical Systems	Mobile Robotics	Elec
2	CSSE with Hardware			DC Circuits and AC Circuits		Robotics Engineering	Artificial Intelligence	Elec
3	CSSE with Mechanics			Conservation & 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	Digital Systems	Cap. Desn. Crdts.
9	ME with Programming		Kinematics	Object-oriented Software Dev.	Data Structures and Analysis	Robotics Engineering	Mobile Robotics	Cap. Desn. Crdts.

Track 4 provides CPE majors with control theory, more software development, and some mechanics. EE majors can select track 5 to focus on software development. EE or CPE majors can take tracks 6 or 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.

ME majors are already required to take Mechatronics and Controls. Those who pursue track 8 will learn more about electronics, digital systems, and device modeling. Those who pursue track 9 gain software experience similar to EE majors in track 5.

Students have enrolled in all of the nine tracks, and thus far, the most popular ones are tracks 4 and 9.

Students in most tracks supplement their expertise in a chosen track with a robotics-related elective. They may choose any course from Table 2 not already required for their major or elsewhere in their track. Additionally, they may choose any course from Table 3.

Required Courses

The faculty advisors for the robotics minor teach the four courses that are integral to most of the tracks of the curriculum. All robotics minors take *Introduction to Robotics*

Programming and *Mechatronics* and at least one of *Robotics Engineering* and *Introduction to Mobile Robotics*.

Table 3: Robotics Electives**.** Graduate-level courses, for depth, are denoted as (g).

Computer Science	**Electrical & Comp. Eng**.
Computer Vision Image Recognition Swarm Intelligence Teamwork and Robotics	Signals and Systems Discrete-time Control Systems (g) Modern Control Systems (g)
Mechanical Engineering	**Physics & Optical Eng.**
Advanced Control Sys (g) Advanced Kinematics (g)	Advanced Image Processing (g)

From a high level perspective, these courses cover the overarching areas in robotics theory including software, hardware, controls and design. *Introduction to Robotics Programming* teaches the basics of software development on a Create robot (software). *Mechatronics* teaches the application of microprocessors and microcontrollers and digital electronics to design embedded control systems (hardware). *Robotics Engineering* focuses on the design of a robot with topics such as kinematics, control, operation and sensing (design). Finally, *Introduction to Mobile Robotics* teaches concepts in feedback control and behavior-based robotics (controls).

CSSE120R – Introduction to Robotics Programming is the first required course for the minor and is a 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 Create robots, using both the actuators and sensors. Eight sections of CSSE120R have been offered over two years. Projects have included line following, environment mapping, PID control, and tracking other robots.

ME430-Mechatronics is required for all mechanical engineering students and all robotics minors, regardless of their major. 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. It is very multidisciplinary, allowing mechanical engineers the opportunity to develop their C programming skills and allowing software engineers the opportunity to learn to interface with hardware.

ME435 – Robotics Engineering is a capstone course that is primarily focused on the robot controller firmware code that runs on a robotic arm. The course covers the communication of a microcontroller to a MATLAB GUI, reading position encoders to track position and velocity, developing a communication protocol for the robot in C, and hitting target velocities and positions through PID control. The course starts from a very low level of development and goes through each component of a typical robotic system controlled by a graphical user interface on a PC.

ECE497- Introduction to Mobile Robotics is a project-based course where the students develop basic behaviors and control architecture for a mobile robot. The students use feedback control to correct for odometry error and use sensor feedback such as distance and temperature to create behaviors including obstacle avoidance, wall and line following, and homing. Robots are programmed using services from the Microsoft Robotics Studio in C#. The course lectures and labs focus on the development of algorithms and application of robot theory including robot components, sensors, locomotion, navigation, mapping and other key topics in robotics research.

Collaboration

In an effort to insure adequate content coverage of the core topics of the curriculum, the PIs have discussed all of the syllabi for the courses, and have sat in on some of each others' courses. Furthermore, the advisors have begun to cross-teach the core courses. After sitting in on *Introduction to Robotics Programming* and co-developing projects for it, the ME professor taught it twice; once in the same quarter as the CS professor and once solo. He also manufactured infrared transmitters for the Create robots. Likewise, the CS professor sat in on the Mechatronics course and then taught it in the same quarter as the ME professor. This collaboration was received very well by the students in the other departments, who gave very positive course evaluations in each case. The instructors intend to continue teaching each others' courses in the future.

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. To this end, we created a robotics senior design sequence (ROBO410-420-430). This model was inspired by a previous senior design project in which an ME major worked with a team of CS majors on the implementation of a robot to deliver sodas from a web-based vending machine to professors' offices.

All three departments approved of this course as a substitution for their single-discipline senior design sequences. In order to meet the departmental requirements, this course had to resolve differences in sequences' start and end times, 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. In computer science and software engineering, design theory is provided during the senior sequence. In the other programs, design theory is part of courses leading up to senior design and the senior design course is more of a practicum.

In addition, 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. Note that the issue was not quite as simple as allowing students to take a senior design sequence in another department instead of the usual one. The students were expected to meet their own department's standards for senior design while also serving as the robotics team's expert in their field.

In 2009-2010, two teams of four enrolled in the ROBO4x0 sequence. These teams are comprised of EE, CPE, and ME students. One project involves the design and control of a remote-controlled robotic manipulator at the Terre Haute Children's Museum. An extension to the project is an autonomous mode for the manipulator, designed to catch children's attention when it is not being used. The second project is the design and control of an intelligent caster system for theater set design. The project powers set pieces weighing up to 1500 pounds and moves them on the stage through wireless control, making the set pieces appear to move on their own. The first set piece driven was a pirate ship that moves across the stage during the performance.

Accreditation

The robotics minor assists participating students in achieving the long-term *objectives* of their individual degree programs by scaffolding their existing knowledge. For example, the minor develops students' ability for independent learning, effective written and oral communication skills, the use of contemporary skills of the engineering profession, the completion of a client-sponsored team design experience, and effective collaboration in small teams. These qualities are closely aligned with ABET criterion 3 program outcomes for engineering programs including the ability

- to design a system within realistic constraints,
- to function on multidisciplinary teams,
- to identify, formulate, and solve engineering problems.

Student Interest

Initial Reception

The robotics minor has been very well received by students, faculty, and employers. In fall 2009, just a year after inception of the minor, the incoming freshman class was surveyed about programs they had heard about prior to coming to campus. Of the 446 students, 59 (13.3%) had heard of the robotics minor, and 30 (6.8%) indicated that the minor affected their decision to attend our institution. These high percentages reflect our advertising and recruitment efforts during the first year and beginning of the second year: we promoted the minor at open houses for prospective students, mailed brochures to the incoming freshmen intending to pursue the five robotics-related majors, held a preview session for CSSE120R during orientation, and held an optional informational meeting during the fall.

Introduction to Robotics Programming

Students are attracted to the CSSE120R Introduction to Robotics Programming course. Of the 167 students who have taken CSSE120R, 87 are already required to take CSSE120 for their CSSE and ECE majors, and so can substitute the course in their plan of study. However, the other 80, including 50 ME majors, are not required to take it for their major. This is a substantial increase; for example, the number of ME majors taking CSSE120 in the year before the introduction of CSSE120R was only 9 (of 127).

We surveyed CSSE120R students at the end of the course about their experience in the course. We used a 5-point Likert scale and obtained a response rate of 41%. Of those students, 86% agreed or strongly agreed with the statement: *I chose Intro to Robotics Programming due to my interest in robotics*. Of the students surveyed in the first year, 69% stated that they knew about the minor. This increased to 78% during the second year, showing the effectiveness of the increased marketing.

Enrollment in Minor

At the informational meetings in fall 2008 and 2009, students completed a brief survey regarding their level of interest (1 = “just curious”, 2 = “interested”, 3 = “I will do this”). Table 4 shows the number of students who have expressed high interest in the minor by indicating an interest level of 3 on the survey. The number of interested freshman (32) is consistent with the number (30) obtained in the survey to all freshmen. Higher interest from the students in their first and second years is expected because they knew about the minor from the onset and could plan their schedules accordingly. The total of 75 students represents 4.1% of the student body. Of these, 34 have also completed and signed “declaration of intent to pursue a minor” forms, which shows a higher level of commitment.

Table 4: Students who have expressed high interest in the robotics minor by year and department.

Year of Graduation	ME	ECE	CSSE	Total
2009	3	0	0	**3**
2010	6	2	0	**8**
2011	8	6	1	**15**
2012	9	7	3	**19**
2013	19	7	6	**32**
Total	**45**	**22**	**10**	**77**

First Graduates

Three students completed the robotics minor in spring 2009. Two of the graduates are working for companies in automation and robotics consulting. The third student is working in robotics research. The students planning to graduate in spring 2010 include a CPE major who will start a master’s degree in robotics in the fall, an EE major who will work as a systems engineer, two ME majors who will work as automation engineers, and an ME major who will work in robotic assembly.

Assessment

The skills that our students should have upon completion of the program (Table 1) were assessed using various instruments.

Students obtain *a deep understanding of their field* by successfully completing the requirements of their major.

Students gain *focused expertise in robotics* by completing the courses in one of the robotics tracks.

Students can *program a robot*. Beyond the introduction to robotics programming, all minors program robots at an advanced level in at least ECE497 or ME435.

Students have expressed confidence in programming robots. Of CSSE120R students surveyed, 81% agreed or strongly agreed with the statement *After taking this course, I am satisfied with my ability to program and develop software*.

Students can *develop an embedded system from scratch* with sensors, control, and actuators. All minors develop this skill in ME430 Mechatronics.

Students can *work with peers from other disciplines*. Since this was a motivating factor in the development of the program, we used many instruments to measure the frequency and ability of students working on multidisciplinary teams. In CSSE120R Intro to Robotics Programming, 32 of 43 student project teams over two years were comprised of students from multiple departments. Of students surveyed, 90% agreed that *after taking this course, I feel I can function effectively on projects with a multidisciplinary team*. In ECE497 Mobile Robotics, 9 of 20 student project teams over three years were comprised of students from multiple departments. We will have additional qualitative and quantitative data at the end of the year for the multidisciplinary senior design projects from exit surveys.

Conclusions and Future Work

The first years of the multidisciplinary robotics minor have been very successful. Based upon the results and assessment, it is evident that it has been beneficial to the institution, students, and industry partners.

However, some opportunities exist to grow and improve the program. The authors have begun a dialogue with faculty in Biomedical Engineering to explore the feasibility of offering the minor to students in their program. We also plan to expand the program by developing or revising courses in the curriculum, acquiring additional hardware and forming an integrated robotics research laboratory. This laboratory will provide a mechanism for undergraduate and graduate multidisciplinary robotics research and senior design projects.

Lastly, although the senior design projects have been successful, new challenges, not present when advising single-discipline project, have arisen. Some of these challenges relate to the fact that some of the authors have never advised a senior design project, let alone a multidisciplinary one. For example, one student was concerned that his project advisor did not have enough depth in his field to adequately direct his work. Possible solutions to this dilemma include cross-disciplinary advising or creating a repository of best practices for advising senior design projects in each related discipline.

For more details about the program, please see http://robotics.rose-hulman.edu.

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