AC 2009-997: ROBOTICS ENGINEERING: A NEW DISCIPLINE FOR A NEW CENTURY

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Robotics Engineering: A New Discipline for a New Century

Abstract

In the spring of 2007, Worcester Polytechnic Institute introduced a BS degree program in Robotics Engineering. The motivation for the program was two-fold: it addresses the needs of the rapidly growing robotics industry and provides a professional career path matched to growing student interest as demonstrated by numerous high school robotics competitions. The program is a collaborative effort between the departments of Computer Science, Electrical and Computer Engineering and Mechanical Engineering and relies in part on already existing courses. The core curriculum, however, consists of five new "unified robotics engineering" courses. Although Robotics Engineering is not recognized as a distinct engineering field by ABET, the program is designed so that it can be accredited under the "General Engineering" ABET criteria. The new major is already very popular.

1.0 Introduction

As technology changes, the occasion sometimes arises when a new engineering field that either addresses a new technology, combines current areas in a new way, or both, is needed. Not all new degree programs have been a success. However, a few, such as Aerospace Engineering and Computer Science, have been exactly what the relevant industry needed at the time they were introduced.

Worcester Polytechnic Institute (WPI) introduced a BS degree program in Robotics Engineering (RBE) in the spring of 2007. The goals of the program are to educate young engineers for the robotics industry and prepare students for graduate work in robotics. The motivation for establishing the program was two-fold. First, we believe that robotics—meaning the combination of sensing, computation and actuation in the real world—is on the verge of rapid growth due to the dramatic reduction in cost and increasing availability of sensors, computing devices and actuators, and that the rapidly increasing needs in areas such as national defense and security, elder care, automation of household tasks, customized manufacturing, and interactive entertainment, will strongly drive the demand for engineers skilled in robotics. Second, it seems clear that robotics has already "caught on" with the current generation of high school students. Indeed, the strong interest in robotics among high school students is clearly demonstrated by, for example, the large number of successful robotics competitions. For example, in 2007, over 32,000 high school students and their mentors participated in the FIRST Robotic Competition and another 5,500, high school aged students competed in the FIRST Tech Challenge[1]. Botball robotic soccer competitions have included over 40,000 students to date[2]. Other robotics events, such as BattleBots IQ[3], Robocup and Boosting Engineering, Science and Technology (BEST) Robotics with over 10,000 students yearly[4], also illustrate the high level of interest. Robotics also appeals to younger students who in some cases become engaged with robotics before entering high school. The robots.net Robotics Competition web page lists over a hundred competitions in 2008 alone[5]. It seems clear that a degree in robotics engineering will provide an attractive entry for the current generation of high school students into engineering. It could be argued that the term mechatronics has already been used to capture the fusion of mechanical and electrical engineering—with computing presumably implied. Indeed, mecatronics engineering degrees

have been introduced in Japan, Europe and elsewhere. However, mechatronics has not caught on in the US and, in any case, it does not seem to have the same appeal to young people as Robotics.

After an intense period of consideration and development, the WPI Robotics Engineering program was approved by the WPI faculty in the fall of 2006 and by the Board of Trustees in March of 2007. The program was announced to potential students during the winter of 2007 and admission open-house presentations drew a large number of attendees. Although the window between the formal approval of the program and the deadline for admitting students was relatively short, students admitted in the Fall of 2007 had the option of declaring the program as an intended major. Many students did so.

2.0 Degree Overview, Mission, Objectives and Outcomes

The degree program is a collaborative effort, involving faculty from the departments of Computer Science (CS), Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME) and was designed top-down, starting with goals and objectives. Recognizing that it is impossible to include a comprehensive course of study equivalent to a BS in CS, ECE, and ME in a 4-year degree, the new RBE program provides a solid foundation in each, with applications drawn from Robotics. In keeping with WPI's educational approach, the curriculum engages students early and often in creative hands-on projects.

The core of the program consists of five new courses: an entry-level course and four "unified robotics" courses based on a "spiral curriculum" philosophy, where the students are engaged in increasingly complex designs and the various technical topics are introduced as needed. Each of these courses includes elements of CS, ECE and ME. To add cohesion within courses, each course in the unified sequence has its own focus, such as locomotion, sensing, manipulation, and navigation. Students in the Robotics program also take other required and elective courses, selected from courses already offered by the various engineering departments. In addition, the program includes an entrepreneurship component to prepare future "entrepreneurial engineers."[6] Like all majors at WPI, the program culminates in a capstone design experience wherein students synthesize their accumulated knowledge in a major project. The RBE program is designed so that it can be accredited under the "General Engineering" ABET criteria and as part of designing the program, we developed a Mission Statement, Educational Program Objectives, and Educational Outcomes:

Mission Statement

> The Robotics Engineering program at WPI prepares undergraduates for work and advanced study in Robotics—the combination of sensing, computation and actuation in the real world. Robotics is on the verge of rapid growth, driven by both supply and demand. The supply side is driven by decreasing cost and increasing availability of sensors, computing devices, and actuators. The demand side is driven by national needs for defense and security, elder care, automation of household tasks, customized manufacturing, and interactive entertainment.

Educational Program Objectives

The Robotics Engineering Program strives to educate men and women to;

- Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering.
- Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications.
- Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality.
- Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.

Educational Outcomes

Graduating students will have;

- an ability to apply broad knowledge of mathematics, science, and engineering,
- an ability to design and conduct experiments, as well as to analyze and interpret data,
- an ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
- an ability to function on multi-disciplinary teams,
- an ability to identify, formulate, and solve engineering problems,
- an understanding of professional and ethical responsibility,
- an ability to communicate effectively,
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
- a recognition of the need for, and an ability to engage in life-long learning,
- a knowledge of contemporary issues, and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

3.0 Program Structure and Curriculum

WPI operates on a somewhat unusual academic calendar where each semester is split into two seven-week terms, during which students take three very intense courses. Terms A and B are taught in the fall (September to December) and terms C and D are taught in the spring (January to April).

The Robotics Engineering curriculum consists of five courses in robotics plus several required engineering course in the fundamentals of electrical and mechanical engineering as well as computer science. The students must also fulfill the WPI general educational requirements, which consist of six courses in the humanities, two in social sciences, twelve courses in mathematics and sciences and a three course equivalent junior project. The two sample schedules shown in Figure 1 illustrate that the program is reasonably flexible, allowing students to start taking robotics courses in either the first or the second year.

Sample Schedule 1

Year	A Term	B Term	C Term	D Term
Freshman	MA 1021	MA 1022	MA 1023	MA 1024
	PH 1110/1	HUA	HUA	ECE 2022
	HUA	**RBE 1001**	CS 1101	PH 1120/1
Sophomore	**RBE 2001**	**RBE 2002**	HUA	MA 2051
	CS 2022/MA 2201	HUA	ECE 2801	HUA
	ES 2501	CS 2223	MA 2621	SS
Junior	ES 3011	SS*	Elective	CS 3733
	RBE 3001	**RBE 3002**	Elective	Elective
	IQP	IQP	IQP	Elective
Senior	Elective	Free	Free	Social Implications
	Entrepreneurship	Elective	Elective	Free
	MQP	MQP	MQP	Free

Sample Schedule 2

Year	A Term	B Term	C Term	D Term
Freshman	MA 1021	MA 1022	MA 1023	MA 1024
	PH 1110/1	PH 1120/1	CS 1101	**RBE 1001**
	HUA	HUA	HUA	HUA
Sophomore	CS 2022/MA 2201	MA 2051	**RBE 2001**	**RBE 2002**
	ES 2501	ECE 2022	ECE 2801	CS 2223
	HUA	HUA	MA 2621	SS
Junior	**RBE 3001**	**RBE 3002**	Elective	Elective
	ES 3011	SS*	Elective	Elective
	IQP	IQP	IQP	CS 3733
Senior	Entrepreneurship	Free	Free	Social Implication
	Elective	Elective	Elective	Free
	MQP	MQP	MQP	Free

Figure 1. Two sample schedules showing how students can obtain a BS degree in Robotics Engineering. MA identifies mathematics courses, PH is physics, HUA is humanities and arts, SS is social science, IQP is three-course equivalent junior project and Free is free electives. The Robotics program consists of robotics (RBE), computer science (CS), electrical and computer science (ECE) and engineering science (ES) courses, an entrepreneurial course, a three-course equivalent senior project (MQP) and Electives.

The essence of the program is captured in five courses, consisting of Introduction to Robotics at the 1000 level (1st year) followed by a four-course Unified Robotics engineering core sequence at the 2000 and 3000 levels (sophomore and junior years). Each course is three credit hours. These course need to be taken in order and each builds on the preceding courses. Thus, although all the RBE courses are open to students from other disciplines, the prerequisite requirements make it difficult for those students to take all but the first two or possibly three. Other courses are required from each of the participating departments to ensure technical breadth and strength. The new required RBE courses are:

RBE 1001. Introduction to Robotics

Multidisciplinary introduction to robotics, involving concepts from the fields of electrical engineering, mechanical engineering and computer science. Topics covered include sensor performance and integration, electric and pneumatic actuators, power transmission, materials and static force analysis, controls and programmable embedded computer systems, system integration and robotic applications. Laboratory sessions consist of hands-on exercises and team projects where students design and build mobile robots.

RBE 2001. Unified Robotics I.

First of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is the effective conversion of electrical power to mechanical power, and power transmission for purposes of locomotion, and of payload manipulation and delivery. Concepts of energy, power and kinematics will be applied. Concepts from statics such as force, moments and friction will be applied to determine power system requirements and structural requirements. Simple dynamics relating to inertia and the equations of motion of rigid bodies will be considered. Power control and modulation methods will be introduced through software control of existing embedded processors and power electronics. The necessary programming concepts and interaction with simulators and Integrated Development Environments will be introduced. Laboratory sessions consist of hands-on exercises and team projects where students design and build robots and related sub-systems.

RBE 2002. Unified Robotics II.

Second of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is interaction with the environment through sensors, feedback and decision processes. Concepts of stress and strain as related to sensing of force, and principles of operation and interface methods for electronic transducers of strain, light, proximity and angle will be presented. Basic feedback mechanisms for mechanical systems will be implemented via electronic circuits and software mechanisms. The necessary software concepts will be introduced for modular design and implementation of decision algorithms and finite state machines. Laboratory sessions consist of hands-on exercises and team projects where students design and build robots and related sub-systems.

RBE 3001. Unified Robotics III.

Third of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is actuator design, embedded computing and complex response processes. Concepts of dynamic response as relates to vibration and motion planning will be presented. The principles of operation and interface methods various actuators will be discussed, including pneumatic, magnetic, piezoelectric, linear, stepper, etc.

Complex feedback mechanisms will be implemented using software executing in an embedded system. The necessary concepts for real-time processor programming, re-entrant code and interrupt signaling will be introduced. Laboratory sessions will culminate in the construction of a multi-module robotic system that exemplifies methods introduced during this course.

RBE 3002. Unified Robotics IV.

Fourth of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is navigation, position estimation and communications. Concepts of dead reckoning, landmark updates, inertial sensors, vision and radio location will be explored. Control systems as applied to navigation will be presented. Communication, remote control and remote sensing for mobile robots and tele-robotic systems will be introduced. Wireless communications including wireless networks and typical local and wide area networking protocols will be discussed. Considerations will be discussed regarding operation in difficult environments such as underwater, aerospace, hazardous, etc. Laboratory sessions will be directed towards the solution of an open-ended problem over the course of the entire term.

Research on engineering education has provided us with a considerable understanding of the many issues involved in keeping students interested in engineering, delivering material effectively and stimulating creativity. It is, in particular, fairly well established that the structure of the curriculum plays an important role in overall student satisfaction and retention and that early introduction to engineering (principles or content) generally helps[7,8,9]. It is also well understood that different teaching methods appeal to different learner types and that generally all people learn more in an environment where the material is presented in a variety of ways[10,11] and that creativity and innovation can be taught, or at least stimulated, in a properly structured course[10,12,13,14]. As a result, the robotics course offers early introduction to the breadth and depth of robotics engineering. The courses consist of a blend of lectures and projects, emphasize creativity and innovation, and focus on technology that has an obvious impact on how people live.

Since the initiation of the RBE major, RBE 1001, RBE 2001 and RBE 2002 have been taught several times with some “tweaking” occurring along the way. RBE 3001 and RBE 3002 are being taught for the first time during the 2008/2009 academic year. Student course evaluations generally indicate a high level of student satisfaction with the courses, particularly for RBE 1001 and RBE 2002 (generally well over 4, on a scale of 1-5). Ratings for RBE 2001 have been high, but slightly lower. As expected the overall satisfaction with the course usually correlate well with the students rating of the instructor. The students are also asked how many hours they spend on the course and a significant fraction of the students report spending over 21 hour per week on the course. On the average, this fraction is highest for RBE 2001, suggesting that the reason for a somewhat lover overall satisfaction with that course is that the workload may be perceived to be higher than in other comparable course. Anecdotal evidence also suggests that this may be the case. An extensive review of the RBE courses, focusing on what we have learned teaching them and how the courses need to change, is scheduled for the summer of 2009.

In addition to required and recommended course work, WPI requires all students to complete a senior-level project in their major field of study. For RBE students, this constitutes a capstone design experience in Robotics Engineering. Students typically work in teams of two to four students, although single-person projects and larger teams are also possible. A faculty member in the major advises the work. The project work itself typically starts with a formal project proposal, including literature review, clearly defined approach, and schedule with milestones. Projects conclude with a report and presentation to faculty and students. In some cases project reports become conference papers. Project ideas come from several sources: faculty may have topics that relate to their research or other interests, industry often sponsors projects (and is charged a project fee for the privilege), and students may explore their own project ideas with faculty approval. Industry sponsored projects are particularly valuable since the sponsor gets a close look at a potential future hire and also gets the opportunity to implement a small project that they otherwise lack the staff to commit to. Students enjoy the experience and find themselves well prepared for future employment or graduate school. Even before the introduction of the RBE program, students from various majors at WPI have been working on robotics projects, such as a solar-cell/rechargeable fuel cell powered robot and a roof inspection robot.

We subscribe to the belief that robotics will be the next growth industry, and thus we require RBE program students to take a course in Entrepreneurship. Although one course certainly is not sufficient for those who intend to form their own businesses, we strongly believe that engineers need to understand the business contexts within which they operate and believe that requiring a course in entrepreneurship will help students see opportunities that may not have been visible to them otherwise. Industry has reacted with great enthusiasm to the entrepreneurship component.

5.0 Institutional Impact

For a private university like WPI, the ability to attract a large number of high quality students is of great concern. The Institute is a long-time supporter of the FIRST and other robotics competitions. Even before the introduction of the RBE program, WPI had staff dedicated to such support. The introduction of the robotics program and its success has required additional support and the institution has hired both new staff and faculty to meet the need. Here we will not discuss the specific resource needs in any detail (those have been discussed previously[15]) but focus on the impact of the introduction of the program on the enrollment at WPI as a whole and in the there majors supporting the program.

Students entering WPI in the fall of 2007 had the opportunity to declare Robotics Engineering as their major, even though the program had only been "on the books" since the previous spring. Students entering WPI do not have to declare a specific major (and a large number come in without doing so) but most do declare near the end of their first year. Table I shows the number of declared majors in the fall of 2007 and 2008 for the RBE program as well as Computer Science, Electrical and Computer Engineering and Mechanical Engineering. Also shown is the total size of the entering class for WPI as a whole and the number of first year students declaring an interest in engineering but who have not picked a specific major. Generally there is a large number of undeclared students in the fall, many of which have selected mechanical engineering

as they start their sophomore year. In the fall of 2007, when the RBE program had just started, the RBE program had a relatively small number of students. As incoming students decided their major the number grew rapidly and by the Fall of 2008, the sophomore class had 47 students. Several juniors had also switched into RBE, as well as a few seniors.

Although we do not have detailed data on where the juniors came from, the numbers for the rest of the majors indicate that they most probably came from ME, which lost 21 students from the class of 2010, CS, which lost 13 and ECE, which lost 6. For the most part the introduction of the RBE major seems to have had little impact on the majors selected by the class of 2011, where both ECE and CS saw increase of the previous year and ME saw only a small decrease that it well within the range of the usual fluctuations in the class size. Although it is still too early to tell what the ultimate number of students in the class of 2012 (entering in the fall of 2008) will select RBE, enrollment in the first robotics class, RBE 1001, suggests that it will be significantly larger than the number in the table. When the data was assembled a significant number of first year students still had to select a major and it seems likely that they will select RBE, along with ME.

Major	**Year**	**Class Year**			
		2012	2011	2010	2009
RBE	2007		7	4	5
	2008	28	47	22	3
ME	2007		99	165	139
	2008	114	131	144	143
CS	2007		69	65	57
	2008	75	60	52	59
ECE	2007		71	72	76
	2008	66	79	66	92
WPI	2007	Total entering: 808		Engineering undecided: 140	
	2008	Total entering: 918		Engineering undecided: 167	

Table I. Enrollment as reported at the fall of 2007 and 2008 by the WPI Registrars Office.

While it is difficult to detect any major effect of the RBE program on the enrollment in the other engineering programs at WPI, its effect on the overall enrollment has been dramatic. WPI has recently embarked on a plan to slightly expand its incoming class size and the intention was to enroll about 800 students in the class of 2012. The institution competes for students with several well-known technological universities and usually admits significantly larger class than eventually enrolls. Nevertheless, the Institution uses relatively well-tested admission and financial aid strategies to achieve the target class size and a long history of successfully enrolling the target class size. In 2008, however, about one-hundred more students than expected enrolled, coming from a geographically more diverse area than in earlier years. While the reasons could be many, there is little doubt that the introduction of the RBE major and the publicity that its introduction generated contributed significantly to this increased popularity of the Institution.

6.0 Conclusions

The introduction of the robotics degree at WPI is a direct and explicit response to the success of FIRST and other robotic competitions in generating excitement among high school students, as well as to the growth of the robotics industry. Furthermore, we believe that those individuals and nations that can convert technological know-how into products will reap the economic benefits of smart electromechanical systems. To do so, technological proficiency is necessary, but not sufficient. The added ingredient is the presence of individuals with the creativity to imagine new products, the preparation to engineer them and the desire to see the products to market. The new degree program will provide a solid foundation in state-of-the-art technology, give sufficient hands-on experience to build confidence and stimulate the imagination, and foster the entrepreneurial spirit that leads to the establishment of start-up companies and creation of jobs.

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