AC 2010-525: A ROBOTICS ENGINEERING M.S. DEGREE

Michael Gennert, Worcester Polytechnic Institute

Prof. Michael A. Gennert is Department Head of the Computer Science Department and Director of the Robotics Engineering Program at Worcester Polytechnic Institute, where he is Associate Professor of Computer Science and Associate Professor of Electrical and Computer Engineering. He has worked at the University of Massachusetts Medical Center, Worcester, MA, the University of California/Riverside, General Electric Ordnance Systems, Pittsfield, MA and PAR Technology Corporation, New Hartford, NY. He received the S.B. in Computer Science, S.B. in Electrical Engineering, and S.M. in Electrical Engineering in 1980 and the Sc.D. in Electrical Engineering in 1987 from the Massachusetts Institute of Technology. Dr. Gennert is interested in Computer Vision, Image Processing, Scientific Databases, and Programming Languages, with ongoing projects in biomedical image processing, robotics, and stereo and motion vision. He is author or co-author of over 90 papers. He is a member of IEEE, ACM, NDIA Robotics Division, and the Massachusetts Technology Leadership Council Robotics Cluster.

William Michalson, Worcester Polytechnic Institute

Michael Demetriou, Worcester Polytechnic Institute

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Abstract

There is an increasing demand for creative scientific, engineering, and management talent to meet national needs. We believe that the best way to educate professionals for leadership roles is in a unified multi-disciplinary curriculum. This paper describes one such program, a Master of Science degree in Robotics Engineering at Worcester Polytechnic Institute, whose goal is to prepare men and women for technical leadership in the robotics industry and research in robotics.

The program, launched in fall 2009, develops competence in electro-mechanical-computational systems and an awareness of management systems. It constitutes a multi-disciplinary effort by faculty in Arts & Sciences (Mathematics and Computer Science), Engineering (Electrical & Computer Engineering and Mechanical Engineering), and Management. The program is organized around a technical coursework core with select science and engineering electives. Technical strength is supplemented by organizational and management principles embodied in context courses in Systems Engineering and Management. The program culminates in individual capstone projects that take the form of a thesis, directed research, or practicum with written report. In all cases, a public oral presentation is required. A B.S./M.S. option allows the program to be completed in a single additional year of work past the Bachelor's degree.

By using existing courses where appropriate, we were able to start the program by developing only two new courses, Foundations of Robotics and Robot Dynamics, supplemented by special topics, independent study, and other project work. We anticipate adding new courses as the program grows, additional faculty join the program, and as we introduce a Ph.D. in Robotics Engineering. Initial response to the program by students and industry has been very positive, and the program shows great promise to contribute significantly to meeting future engineering workforce needs.

1. Introduction

There is an increasing demand for creative scientific, engineering, and management talent to meet national needs. We believe that the best way to educate professionals for leadership roles is in a unified multi-disciplinary curriculum. This paper describes one such program, a Master of Science degree in Robotics Engineering (RBE) at Worcester Polytechnic Institute (WPI).

The M.S. program is a natural successor to the B.S. program in Robotics Engineering that was introduced in 2007[1,4]. The B.S. offers what we believe to be excellent undergraduate education in preparation for careers in robotics and related fields. However, there is a limited amount of scientific and engineering material that one can cover in a 4-year degree while still providing the rich undergraduate experience necessary to become a well-rounded citizen in today's society. The RBE M.S. degree goes beyond the B.S. to prepare graduates for technical leadership roles in the robotics industry and research in robotics.

Combined with the existing B.S., planned-for Ph.D., faculty hires, and externally sponsored research, the M.S. in Robotics Engineering is a key component of a full-fledged robotics initiative.

1.1. Motivation

The development of the M.S. program in Robotics Engineering was motivated by several considerations. Foremost was to **appeal to student interest, including B.S./M.S.** Educational institutions must continuously understand where student interest lies and offer relevant, academically sound programs. Currently enrolled undergraduates have expressed interest in graduate studies in robotics. Some have already applied for admission to graduate school as interdisciplinary students. Formalizing the RBE M.S. program enables universities to take full advantage of this pipeline as well as draw graduate students from outside.

A second motivator was to **strengthen ties with the growing robotics industry.** Given the inherent delays in setting up and implementing educational processes, it is not sufficient to respond to industry needs; the successful university must also anticipate them where possible. As the robotics industry matures[2], it will need increasingly highly trained professionals at all levels, hence there exists an opportunity to supply industry with the talent it needs as it needs it. The RBE Advisory Board has expressed strong support for a M.S. program and has contributed to the development of the program goal and objectives.

Other factors operate in the university's self interest. Among them are: **Maintain leadership in robotics,** solidifying WPI's leadership position in robotics education nationally following our pioneering work establishing an undergraduate major in robotics[3]. The M.S. will also **lead to a Ph.D. program**, currently under development, for which the thesis-based M.S. program will constitute excellent preparation. As the robotics initiative expands, the M.S. program will **provide a source of Teaching Assistants for the RBE B.S. program.** Currently, the CS, ECE, and ME Departments supply RBE graduate student Teaching Assistants and undergraduate Senior Assistants. It would be preferable to have a pool of potential RBE M.S. and Ph.D. TAs who are better prepared in robotics. As there is much competition for top faculty in robotics, and equally intense competition for funding among faculty, it is important to **support faculty research** through a strong graduate program in Robotics Engineering that will attract and retain the best robotics faculty, and to enable them to perform the most advanced research. A final consideration, not to be overlooked as one seeks administrative support for a venture, is **generate financial returns.** An RBE M.S. program can easily generate more tuition revenue than it costs to deliver. When the other returns listed above are considered, the benefits far outweigh the costs.

2. Process

Having identified the M.S. in Robotics Engineering as a target, it is tempting to survey current resources, such as existing courses, and ask how they can be used to accomplish the goal. We argue that this is the wrong approach. Such a bottom-up view can lead one to overlook alternatives, freeze existing practices that were not necessarily geared toward the program, and

lead to a mismatch between goals, objectives, and implementation. Better is to adopt a top-down approach as follows:

1. Bring faculty together to agree on vision.
2. Draft a Mission Statement.
3. Identify what graduates will be expected to do upon degree completion.
4. Define broad Program Goals.
5. Define Program Educational Objectives.
6. Draft Curriculum.
7. Identify Existing / Needed Resources.
8. Develop Business Plan.

This formula has proven successful for several educational program innovations[1,6]. In practice, one does not follow quite so clear a top-down approach, as it is often necessary to refine and revise in a non-linear matter. However, as a guiding principle, the top-down approach can help maintain planning focus.

In the current case, tasks 1 and 2, Bring faculty together and Draft mission statement, were already met through the B.S. program. The other tasks are treated in turn.

2.1. Tasks 3 and 4: Expectations and Goals

Identifying what graduates would do proved to be less straightforward than one might expect. Clearly, M.S. graduates should be capable of occupying more demanding positions than B.S. graduates, such as working more at the "systems" level than at the "component" level. Ultimately, we settled on preparation for leadership as a key concept for the M.S. program. As master engineers, graduates should be able to lead projects and teams, demonstrating both technical and managerial competence. As potential Ph.D. candidates, graduates should be ready to conduct state-of-the-art research. This lead naturally to the program goal:

- The goal of the Master of Science program in Robotics Engineering is to prepare men and women for technical leadership in the robotics industry and research in robotics.

2.2. Task 5: Objectives

The program's objectives reflect the depth and breadth needed to realize the goal. Working in a multi-disciplinary domain such as robotics requires some background in computing, electrical and mechanical systems, and relevant mathematics. Students do not need proficiency in each, but should understand the core concepts of each domain.

In preparation for technical and managerial leadership roles, objectives include management and systems engineering to provide context to the engineering process. These are "Plus Courses" in the terminology of Professional Science Master's programs[5].

Finally, consistent with our philosophy of project-based education, we expect students to have practical experience. A summative capstone can assure that students solve a real engineering problem, while providing a challenging integrative experience for students.

Thus, the program's objectives are to educate men and women to

- Have a solid understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mathematics, and Mechanical Engineering underlying robotic systems.
- Have an awareness of the management and systems contexts within which robotic systems are engineered.
- Develop advanced knowledge in selected areas of robotics, culminating in a capstone research or design experience.

2.3. Task 6: Curriculum

The M.S. program in Robotics Engineering requires 36 credit hours of work. Students may select a non-thesis option requiring a 6-credit capstone design/practicum, or a thesis option requiring a 9-credit thesis. Minimum requirements are:

1. Robotics Core (15 credits)
    - Robotics Foundations (6 credits)
    - Computer Science (3 credits)
    - Electrical and Computer Engineering (3 credits)
    - Mechanical Engineering (3 credits)
2. Engineering Context (6 credits)
    - Management (3 credits)
    - Systems Engineering (3 credits)
3. Capstone / Thesis (6-9 credits)
    - A 6 credit hour capstone design project / practicum or a 9 credit hour thesis.
4. Electives (6-9 credits): Sufficient course work selected from upper-level undergraduate courses and graduate courses in select disciplines to total 36 credit hours.

2.3.1. Thesis Option

The M.S. thesis consists of 9 credit hours of work, normally spread over at least one academic year. A thesis committee is set up during the first semester of thesis work. This committee is selected by the student in consultation with the major advisor and will consist of the thesis advisor, who must be a full-time RBE faculty member, and two other faculty members, at least one of whom is a RBE faculty member, whose expertise will aid the student's research program. An oral presentation before the Thesis Committee and a general audience is required.

2.3.2. Non-Thesis Options

As an alternative to a research-based thesis, students may include a design/research component in their graduate program by completing a 6 credit capstone design project or practicum. The capstone design project must demonstrate significant graduate-level work involving Robotics Engineering, include substantial analysis and/or design related to robotics engineering, and conclude with a substantial written report.

A practicum provides students an opportunity to put into practice the principles that have been studied in previous courses. It is generally conducted off campus and involves a real-world robotics-engineering situation. The project must include substantial analysis and/or design related to robotics engineering and concludes with a substantial written report.
Students completing a capstone design project or practicum must deliver a public oral presentation to a committee consisting of the supervising faculty member and two additional faculty members (in the case of a practicum, the on-site liaison and one additional faculty member).

2.3.3. B.S./M.S. in Robotics Engineering

The requirements for the M.S. in Robotics Engineering are structured so that undergraduate students are able to pursue a five-year Bachelors/Masters program, in which the Bachelors degree is awarded in any major offered at WPI and the Masters degree is awarded in Robotics Engineering. Students may double count up to 12 credits for the 5-year Bachelors-Masters program.

2.3.4. Summary of Credit Requirements

	MS Thesis	MS Non-Thesis	BS/MS
Robotics Core	**15**	**15**	**15**
Engineering Context	**6**	**6**	**6**
Electives	**6**	**9**	**9**
Thesis	**9**	**–**	**–**
Capstone Design / Practicum	**–**	**6**	**6**
Double Count	**–**	**–**	**(12)**
Total	**36**	**36**	**24**

2.4. Tasks 7 and 8: Resources and Business Plan

The M.S. program in RBE required the development of only 2 new graduate courses: RBE 500 Foundations of Robotics and RBE 501 Robot Dynamics. With new faculty positions already committed to supporting the rapidly growing undergraduate robotics program, 2 courses / year represents a small increment – 0.67 faculty FTE – that can easily be accommodated by the faculty growth. At current tuition rates and a full-time load of 18 credit-hours / year, the expected 10-15 full-time students per year translates into a tuition revenue stream that equals 3-4.5 times the faculty cost.

We recognize, however, that this represents only a bare-bones course framework, and additional courses will be developed and offered in the future. As the program ramps up, research and teaching assistantships are generated, and industry responds, we project that enrollment could reach 40–60 RBE M.S. students / year. We plan to offer additional advanced robotics courses commensurate with increasing enrollment and expanding faculty interests.

3. Conclusions

At this writing, the M.S. program has been in operation for only a single semester. However, based on student interest, it appears to be headed for success. For example, the first offering of RBE 501 Foundations of Robotics attracted 10 students, achieving a student course evaluation overall rating of 4.33 out of 5.0.

Industry has expressed its support through offers of internships and we believe that the program is well on its way to meeting our fullest expectations and future engineering workforce needs.

4. Acknowledgements

The authors wish to thank the Robotics Engineering faculty at WPI who have worked hard to make the vision of robotics education become reality. In addition, we thank the anonymous reviewers for their constructive comments that have improved the presentation of the paper.

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