Northeastern University

College of Engineering

College of Computer and Information Science

Master of Science in Robotics (MSROB)

LAST UPDATED: NOVEMBER 2017

Introduction and Background

The proposed multidisciplinary Master of Science in Robotics (MSROB) is offered by the College of Engineering (COE) and the College of Computer and Information Science (CCIS), and co-housed in Departments of Mechanical and Industrial Engineering (MIE), Electrical and Computer Engineering (ECE), and Computer Science (CS). The proposed program is designed to give students a comprehensive introduction to the algorithms, sensors, control systems, and mechanisms used in robotics. Robotics, integration of sensing, computation and actuation in the physical world, has an ever-growing impact on modern technology, human health and manufacturing. This program leverages multiple existing courses and faculty expertise in MIE, ECE and CS Departments as described throughout the proposal.

Master of Science in Robotics (MSROB) At A Glance

The proposed MS in Robotics program is a multidisciplinary program with the following three concentrations, 1) *MS in Robotics with Concentration in Mechanical Engineering*, 2) *MS in Robotics with Concentration in Electrical Engineering*, and 3) *MS in Robotics with Concentration in Computer Science*. Each student will be required to take a total of 32 SHs of coursework that includes four core courses covering the fundamentals of robotics, and four elective courses from a variety of areas in both COE and CCIS, and across the university, to explore fundamental robotics disciplines and technical applications. A minimum GPA of 3.0 will be required for degree completion. MSROB graduates will be well positioned to get engineering or management jobs in the growing field of robotics or to progress into doctoral degrees in robotics or related areas.

Similar to most MS programs in COE, graduate students accepted into any of the concentration in MSROB can choose one of the three options: i) *coursework only track (32 SH course work)*, ii) *project track (28 SH course work plus 4 SH project)*, or iii) *thesis track (24 SH course work plus 8 SH thesis)*. Students who want to pursue project or thesis options must find, within their first year of study, a faculty member or a research advisor who will be willing to direct and supervise a mutually agreed research project or MS thesis. Moreover, students who receive financial support from the university in the form of a research, teaching, or tuition assistantship must complete an 8-semester-hour (SHs) thesis.

Why Master of Science in Robotics

The field of robotics is growing quickly. According to a report by McKinsey, the economic impact of robotics by 2025 could be between $1.7 and $4.5 trillion. There is already a strong interest from our current students in such a program. Many of our undergraduates currently get co-ops at robotics companies. Many

prospective MS students both in COE and CCIS ask about our robotics course offerings. Robotics employers often contact us regarding hiring our robotic students. It is critical for Northeastern to play a larger role in this emerging area. Fortunately, Northeastern has already made a significant investment in robotics by hiring half a dozen new faculty across multiple departments and colleges. There already exist six core faculty and an additional twelve affiliated faculty at Northeastern (see www.northeastern.edu/robotics/).

Competition From Other Programs

Given the exponential rise of robotics systems and applications and the high level of employer demand, it is not surprising that several universities have created robotics programs and certificates in the past few years. While the number of programs in this area has increased greatly over the past 3-5 years, demand continues to exceed supply. This is true for companies across the country but also specifically in Boston and the New England area with companies where faculty have collaborations and contacts. Table 1 lists some of the key competitors. For a list of additional MS programs in robotics, pls. see the listing online at: http://www.gradschoolhub.com/best/robotics-engineering-schools/

Table 1. Specific competitor programs

Institution	*Program*	*Focus*	*Courses/Credit*
University of Michigan	MS in robotics	Sensing, Reasoning, Acting	5 core courses + 3 electives and thesis/project
Carnegie Mellon University	MS in robotics, robotics development, and computer vision for robotics	Robotics fundamentals, applications, computer vision	4 core courses + 4 technical electives and project
Georgia Tech	MS in Computational Perception and Robotics	Computer Vision, Robotics	2 core courses + 3 technical electives and project/thesis
University of Southern California	MS in Intelligent Robotics	Robotics	4 core courses + 4 technical electives
Worcester Polytechnic Institute	MS in Robotics	Robotics	4 core courses + 4/2 electives and project/thesis.

Impact on Existing Program at Northeastern

The creation of the MSROB has the potential to draw students from several current MS programs at Northeastern including the Masters in Computer Science (MSCS), the Masters in Electrical and Computer Engineering (MSECE), and the Masters in Mechanical Engineering (MSME). However, since all three of these programs are already at capacity with very competitive admissions rates, this impact should be minimal (for example, the MSCS accepted only 21% of its 2,600 applicants in fall 2015). Moreover, MSROB could make the MSCS, MSECE, and MSME programs even more attractive than they already are by facilitating the introduction of additional robotics courses. Many of our current MS students are already very interested in robotics because they hope to find jobs with major tech firms such as Toyota, Amazon, Google, Apple and Nvidia, to just name a few. Since the additional courses that will be created in support of MSROB will also be available to other MS students, we expect that this will ultimately have a positive effect on all our MS programs. Additional impact at the university could include programs that offer elective course areas. Moreover, the growth of MSROB program will support higher enrollments in elective courses in related technical or contextual areas. Partner colleges will be consulted on the approval of their courses for this program.

MSROB Program Overview And Curriculum

Program Overview: The field of Robotics is fundamentally interdisciplinary, drawing on ideas in computer science, mechanical engineering, and computer and electrical engineering. Consequently, our proposed curriculum integrates courses from each of these areas. There will be six core courses in total, with each department (MIE, ECE and CS) offering two core courses. Each student will be required to take at least four core courses, depending on their concentration (see details next). The MIE core courses will focus on control, dynamics, and kinematics of robots, while the core courses in ECE will focus on systems, mapping, localization, and navigation. The core courses offered by CS will dive into perception, planning, and learning algorithms. These courses will explore the topics above in the context of a variety of real aerial, ground, marine, and manipulator systems. The courses are tailored toward students with a major in either a field of engineering or computer science. Finally, the student will round out their requirements with four technical electives selected from among those listed in Appendix A.

Detailed Curriculum: Students are required to take four of the six core courses plus four, three, or two elective courses based on their track .

- ***Required Core Courses (16 SHs)***

  Must take at least one from each of ME, ECE and CS.
  (4 SHs) ME 5659: Control System Engineering
  (4 SHs) ME 5250: Robot Mechanics and Control

  (4 SHs) ECE: 5698 Mobile Robotics
  (4 SHs) ECE 5698: Robotics Sensing and Navigation

  (4 SHs) CS 5335: Robotic Planning and Perception
  (4 SHs) CS 5XXX: Reinforcement Learning and Decision Making

- ***Elective Courses (16 SHs)***

  Coursework Only Option
  16 SHs from the approved list given in Appendix A

  Project Option
  4 SHs of MS Project or approved Independent-Study course
  12 SHs from the approved list given in Appendix A

  Thesis Option
  8 SHs of MS Thesis
  8 SHs from the approved list given in Appendix A

- ***MS with concentrations in ME, ECE or CS***

  Students choose their concentration (CS, ECE, or MIE) at the time they apply to the program. They must take two core courses from their concentration department. The remaining two core courses must be selected one from the other two concentrations. The elective courses (which are 16 SH for course only track, 12 SH for project track, and 8 SH for the thesis track) are selected from the list of elective courses given in Appendix A.

Program Educational Outcomes

Graduate Students who complete the MS degree will be able to:

1. *Outcome 1:* Understand the planning, perception, and learning algorithms common in robotics and be able to apply these algorithms in the context of mobility and manipulation systems.
2. *Outcome 2:* Understand the kinematics and dynamics of robotic systems and be able to design controllers for these systems.
3. *Outcome 3:* Understand the sensor, actuator, embedded, mapping, localization, and navigation systems commonly used in robotics and be able to build/integrate end-to-end systems.

Admission Criteria

In general, successful applicants to the MSROB program will have a background in Engineering or Computer Science, with a strong background in programming, statistics, and linear algebra. Students will select a concentration department, called "Home Department" — see list of concentrations in the previous sections. The home department, in consultation with the other two departments, will make admissions decisions for all students in that concentration. In order for student to be accepted into MSROB program, at least two departments, including the home department, must provide positive recommendations for the student.

Minimum requirements for an application to be reviewed for admission are:

- An undergraduate degree in MIE, ECE, CS, or a closely related area with a minimum GPA of 3.000
- Statement of purpose including description of relevant work experience.
- GRE: 150V/155Q/4.0A
- TOEFL: 100 (for international applicants with a BS from a non-native English speaking country)
- Two (2) letters of recommendation from professional and/or academic reference.

Assessment Plan

The assessment plan for the new courses in the MSROB uses both direct and indirect assessment to assess how well students are achieving the core outcomes of each individual course.

Direct assessments will include an anonymized assessment of student coursework to be sampled at random from the core courses. Selected work will be cumulative and synthetic to each course, such as final projects. The program faculty will develop quality rubric to assess the outcomes of each course and the level of achievement by current students. Coursework will be sampled annually.

Indirect assessments of the program and new core courses will include standard institutional metrics including but not limited application statistics, enrollment data, completion and persistence rates, TRACE evaluations, student surveys (current and graduate), and student-employer co-op reviews. The program will also conduct student interviews (group and individual) to understand student perceptions of program and course operation.

Resources and Revenue

The MSROB program will be based upon existing resources in the College of Engineering (MIE and ECE Departments) and the College of Computer and Information Science (CS Department).

Program Points of Contact

- MS in Robotics with Concentration in Mechanical Engineering: Prof. Nader Jalili (MIE/COE)

- MS in Robotics with Concentration in Electrical Engineering: Prof. Hanumant Singh (ECE/COE)
- MS in Robotics with Concentration in Computer Science: Prof. Robert Platt (CS/CCIS)

Appendix A: List of Approved Elective Courses[1]

College of Engineering

Mechanical and Industrial Engineering Department (All 4 SHs course, except otherwise noted)

- ME 5240: Computer Aided Design and Manufacturing
- ME 5245: Mechatronic Systems
- ME 5250: Robot Mechanics and Control
- ME 5655: Dynamics and Mechanical Vibration
- ME 5659: Control Systems Engineering
- ME 5665: Musculoskeletal Biomechanics
- ME 6200: Mathematical Methods for Mechanical Engineers 1
- ME 6201: Mathematical Methods for Mechanical Engineers 2
- ME 7210: Elasticity and Plasticity
- ME 7247: Advanced Control Engineering
- ME 7253: Advanced Vibrations
- ME 7350: Graduate Seminar in Robotics (1 SH)
- IE 5630: Biosensor and Human Behavior Measurement
- IE 7270: Intelligent Manufacturing
- IE 7280: Statistical Methods in Engineering
- IE 7315: Human Factors Engineering
-

Electrical and Computer Engineering Department (All 4 SHs course, except otherwise noted)

- EECE 5639: Computer Vision
- EECE 5642: Data Visualization
- EECE 5644: Introduction to Machine Learning and Pattern Recognition
- EECE 5698: Mobile Robotics
- EECE 5698: Assistive Robotics
- EECE 5698: Sensing and Navigation
- EECE 5580: Classical Control Systems
- EECE 7323: Numerical Optimization Methods
- EECE 7335: Detection and Estimation Theory
- EECE 7337: Information Theory
- EECE 7360: Combinatorial Optimization
- EECE 7370: Advanced Computer Vision
- EECE 7397: Advanced Machine Learning

College of Computer and Information Science

- CS 5006: Algorithms
- CS 5100: Foundations of Artificial Intelligence

[1] Other approved 5000 or higher-level courses may be chosen or petitioned to be taken in consultation with faculty advisor.

- CS 5320: Digital Image Processing
- CS 5330: Pattern Recognition and Computer Vision
- CS 5340: Computer/Human Interaction
- CS 6110: Knowledge-Based Systems
- CS 6140: Machine Learning
- CS 6120: Natural Language Processing
- CS 6130: Affective Computing
- CS 6350: Empirical Research Methods
- CS 7140: Advanced Machine Learning
- CS 7170: Seminar in Artificial Intelligence
- DS 5220: Supervised Machine Learning and Learning Theory