COLLEGE OF ENGINEERING
ROBOTICS INSTITUTE
UNIVERSITY OF MICHIGAN

05 September 2021

Dear CoE Curriculum Committee,

With this memo, I am requesting approval for the establishment of a Robotics Undergraduate Major conditioned on the faculty of the College of Engineering approving the establishment of a Robotics Department. Dean Alec Gallimore and ADAA Steve Ceccio anticipate a vote on the department question taking place during the F-21 semester.

Background

Robotics faculty have taken the opportunity of a new department to rethink how to meet the needs of the 21st Century for excellence in both equal opportunity and leading scholarship. To prepare a diverse group of students for the era of Information, AI, Data, and of course, Robotics–all domains where Linear Algebra is the *Lingua Franca*, Robotics introduced ROB 101 Computational Linear Algebra, which promptly won the Provost's Teaching Innovation Prize in its pilot semester. Innovations included: breaking the stranglehold of Calculus and associated AP credits, whose availability is often tied to one's Zip Code; and re-imagining the way mathematics is introduced to first-semester engineering undergrads, by integrating math with programming to allow engineering projects at the "scale of life" (building maps for robot navigation from LiDAR data; building a precipitation surface map inspired by Machine Learning, but based in least-squares and regression; and controlling a planar model of a Segway using optimization).

Values

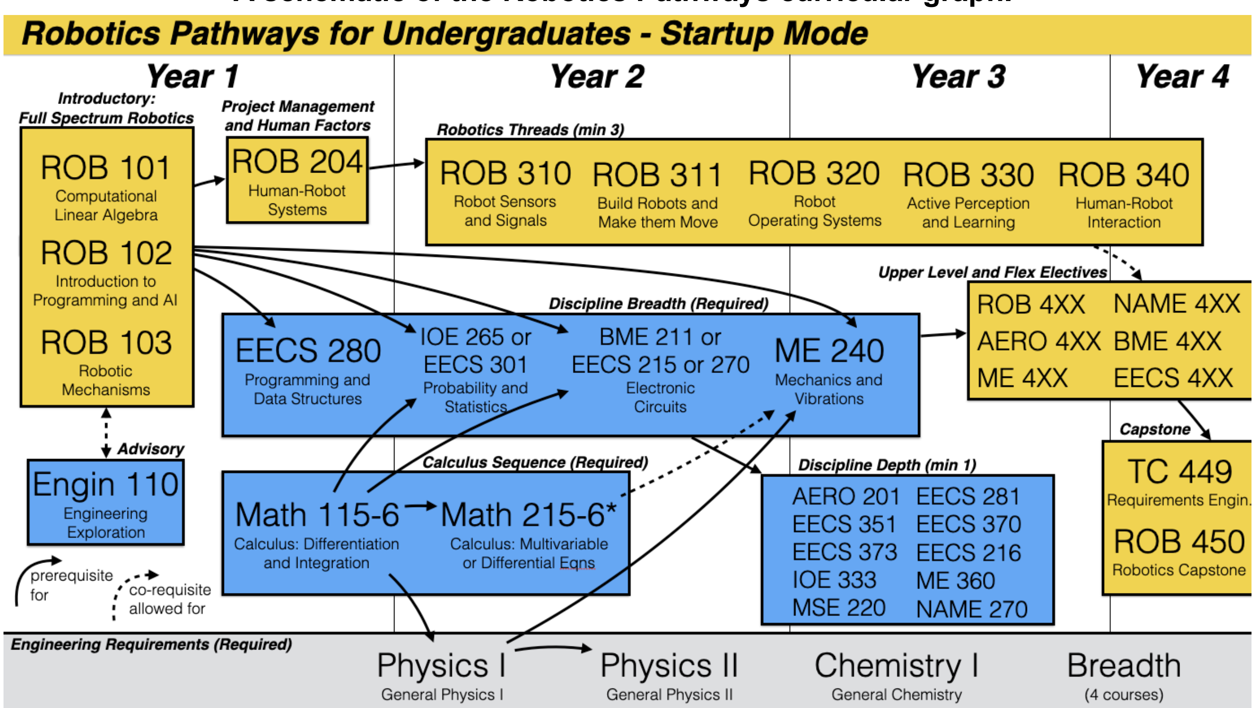
The desire to design a curriculum that favors a student's success being determined by their intellectual ability and drive instead of where one attended high school is being extended to the entire UG Curriculum. The success of ROB 101 in building a bridge with Morehouse is being extended to create a Distributed Teaching Collaborative with MSIs, with explicit planning in course offerings to include remote participation of students from HBCUs, collaborating with them on a summer camp for HS Students run through Morehouse, and placing course content online...not just the videos of the lectures, but the actual course notes and supporting material.

The values of Michigan Robotics foster a culture of compassion to address today's social injustice. Michigan Robotics aims to cultivate the leaders and the best with consideration of personal development at all career stages, innovation in undergraduate and graduate programs, and engagement with partners in K-12 education, minority serving institutions, industry, and the public sector. Robotics faculty actively participate in demographic-specific conferences and venues (e.g., NSBE, SWE, SHPE) to engage students who may not have otherwise considered applying to Michigan. *100% of current faculty and staff who hold appointments in the Robotics Institute have completed the Change it Up! To Stop Anti-Black Racism training module*. I and other Robotics faculty have developed an 11th grade course in cooperation with Detroit metro schools and, as cited above, founded *Distributed Teaching Collaboratives* with HBCUs, which are specifically designed to realize the potential of underserved communities to contribute to-- and participate in--- the field of robotics. Robotics has also invited Ford Motor Company to assist with these efforts, which has generated goodwill all around.

Defining the Discipline of Robotics

The Michigan Robotics Undergraduate Program has been formed for innovation that builds on the foundation of Michigan Engineering and furthers the ethos of ``Robotics With Respect.'' Michigan Robotics aims to meet undergraduate intellectual needs emerging in the 21st Century by inspiring students from their first day on campus and cultivating equal opportunities for a diverse world. Indicators of student interest, both formal and anecdotal, show high interest among undergraduates for a Robotics major. Our society has a growing and unmet demand for people skilled in robotics, as well as artificial intelligence. Michigan is well poised to lead the evolution of higher education to meet these challenges, affect positive systemic change, and prepare future generations for a highly dynamic innovation ecosystem.

A schematic of the Robotics Pathways curricular graph.



Michigan Engineering has a unique opportunity to further its global leadership by defining robotics as a core academic discipline. An undergraduate curriculum of a discipline organizes and disseminates its intellectual foundation. Our aim is to accommodate the learning needs of students who strive to be roboticists, and longer term, ``X+Robotics'' students in existing engineering degree programs who want exposure to robotics. This proposal is only for a major or double major and does not address a minor in Robotics because we currently lack the faculty bandwidth to tackle that important group of students. An undergraduate major creates an acculturation of students into a discipline and its academic climate. The Michigan Robotics Undergraduate Program aims to realize a just, diverse, equitable, and inclusive environment for scholars at all stages of learning, with graduates who improve the human condition throughout their careers.

The Robotics Pathways are organized around the study of embodied autonomous systems that perceive, reason, and act in the physical world. The Robotics Pathways are organized to complement many intersecting disciplines across the academy. The Robotics Pathways have a significant intersection with artificial intelligence and its study of autonomous reasoning systems that make inferences from data and prior knowledge. It is the unforgiving factors of uncertainty in the real world - ambiguity in sensing, nondeterminism in actions, messiness of the natural world - that distinguishes robotics and its academic demands.

The Robotics Pathways introduces two innovations into Michigan Engineering curricular offerings: the Full Spectrum Robotics Introduction and the Robotics Threads curricular and advising model. These innovations are complemented by exposure to the disciplinary breadth of engineering at the intersection of robotics. Students are educated in the core topics of electronics, mechanisms, computation, probability and statistics, and human-robot interaction.

The Full Spectrum Robotics Introduction

The Full Spectrum Robotics Introduction provides a flexible and immersive introductory experience into the discipline of robotics. Aligned with the philosophy of Michigan Engineering for first-year education, this introductory experience exposes students to the foundations for modern engineering through the lens of autonomous navigation for mobile robots:

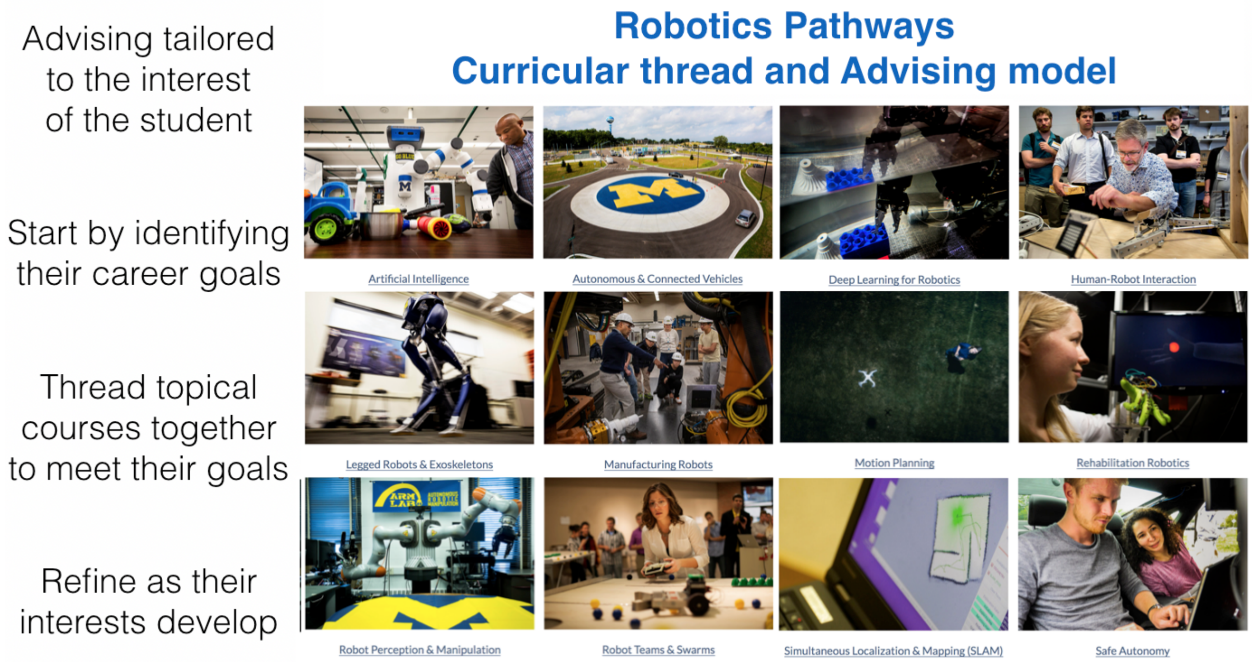
- computational fluency for expressing ideas through coding (coding is believing)
- maker and shop competency for realizing systems that can move in the physical world
- linear algebra as a compelling catalyst into higher mathematics
- human and social dynamics for working in teams to develop solutions for people

In startup mode, the Full Spectrum Robotics Introduction courses are taking shape through courses that have been piloted or are in current development. Robotics 101 (Computational Linear Algebra) is suited to complement traditional and more theoretical linear algebra courses (such as Math 214 and 217) while giving students sufficient preparation for intermediate and upper level courses in Engineering. Robotics 101 provides the mathematical concepts for representing spatial systems, such as for 3D mapping, and large linear systems of equations, such as for bipedal control. Similar in aims to Engineering 101, Robotics 102 (Introduction to AI and Programming) provides an introductory experience to computational thinking and programming in preparation for data structures courses. Robotics 102 conceptualizes computing as graph and graph algorithms that are grounded in various approaches to path planning for mobile robots. In alignment with sections of Engineering 100, Robotics 103 (Robotic Mechanisms) is an introductory real-world design experience to build and control a mobile robot inspired by warehouse robots used in supply chain logistics. Robotics 103 familiarizes students with shop facilities for making physical systems and introduces students to low-level controls and embedded programming. Robotics 204 (Human-Robot Systems) introduces students to the human dimensions of robotics, including introducing human-information processing models to support robotic system design and real-world integration. Robotics 204 presents both the usability of robotics and the structure and workflow for human-centered design to inform project management. Robotics 204 serves as the gateway course into the Robotics Threads, the intermediate level for Robotics majors and eventually, minors.

The structure for the first year in the Robotics program is quite different from the usual first year structure, and there is a concern among some departments that students will be pressured into deciding to pursue Robotics as a major before they come to campus. However, the ROB 100-level sequence is an experiment that is attempting to revise how first year engineering students are taught regardless of discipline. The Robotics Institute is working closely with the ADUE to ensure that the courses meet the goals of the first year program as currently implemented. For instance, ROB 103 (102) meets similar learning objectives as ENGR 100 (101), and is thus an acceptable substitute. ROB 101 is addressing inequities in how we recruit and train engineers, and breaks the stranglehold AP Calculus has on success in majoring in STEM fields. Furthermore, Students who take ENGR 100, ENGR 101, and Math 214 will be accepted into ROB 204, such that not taking the ROB 100-level sequence does not preclude students from majoring in Robotics.

The Robotics Threads Advising and Curricular Model

The Robotics Threads is the curricular and advising model for deeper study into the discipline of robotics for both majors and minors. Among the broad reach of robotics, there are a core set of competencies that lead to many different paths for emerging roboticists and intersections with other disciplines. Further, advising that connects with students and their interests as individuals can combat one of the largest factors preventing diversity: isolation. Towards this end, the Robotics Threads start from the premise of presenting students with possible professional pathways beyond their completion of a major in Robotics. Students can envision what pathway is best for them, and work with their advisor to find a degree-satisfying course plan that will help them achieve their goals. To meet the diverse range of robotics pathways, we have identified the Robotics Threads Intermediate Level courses as core topics in robotics that can be flexibly selected to provide a solid foundation for the discipline of robotics. These courses provide firm grounding in a subset of the core dimensions of robotics that can be built upon for further exploration in upper level courses as well as continued learning into other core areas of robotics.



Sincerely,

Jessy W. Grizzle
Director of Robotics
Jerry W. and Carol L. Levin Professor of Engineering
Elmer G. Gilbert Distinguished University Professor of Engineering
Professor of Electrical Engineering and Computer Science
Professor of Mechanical Engineering (Courtesy Appointment).

Proposal for the Establishment of an Undergraduate Robotics Degree Program at the University of Michigan College of Engineering

Rationale

The academy needs to keep pace with the growing demand for jobs, technology, and innovation: The national and global technology landscape is shifting, and U-M is poised to meet this challenge. The US Bureau of Labor Statistics recently reported that the annual demand for qualified robotics professionals grew by over 13% in 2018 alone. In addition, up to 80% of US industrial employers are facing difficulties filling vacancies for highly skilled technical professionals, including robotics, computer vision, artificial intelligence, and motion control. These statistics are underscored by a growing market. The global industrial and service robotics markets are expected to grow by over 20% year over year (CAGR), reaching a total market of $310B by 2025—the writing is on the wall. The confluence of a gap in skilled workers and a growing market demonstrates the need to rethink technical higher education. That is, a new program is needed that i) provides interdisciplinary training in robotics curated to meet current and future technology demands of the robotics workplace, and ii) provides a college major, a clear designation of skills that will enable graduates to compete for the most promising and highly skilled jobs.

Students are searching for universities that offer robotics undergraduate majors and minors: There is an explosion of interest in robotics-related activities from young people of all ages, and a robotics department will draw these students. Middle and high school students interested in robotics have historically been unable to learn the desired technical content in school, and have instead turned to afterschool programs. FIRST Robotics—a league where teams compete with custom-built robots completing predefined tasks—was developed to meet this growing need. Over the past decade, the number of FIRST Robotics teams has grown by over 40x to over 40,000 teams, including 630 in Michigan. A similar program, VEX Robotics, has expanded to over 50 countries over the same period. These programs have a direct and meaningful impact on participating students. A recent study found that over 95% of students participating in VEX Robotics desired to learn more about robotics and engineering in their future education, including about a third of female participants. While the programs are impressive, they represent a groundswell of interest from younger generations. These students have already demonstrated the lengths they will go to study robotics by pursuing these experiences in their free time outside conventional education. Without a clear and strong emphasis on robotics—namely, a robotics department with an undergraduate major—U-M may struggle to attract these promising students.

Demand at Michigan for Robotics UG Education: Market research shows that as many as 40 percent of current students expressed interest in a Michigan Robotics major or minor, while 25 percent of students who were accepted to Michigan but ultimately enrolled elsewhere indicated that they might have decided differently if Michigan currently offered a Robotics degree program. On one level, this underscores the need, even the urgency, for launching a full undergraduate Robotics curriculum. It also points to some important decisions the College and department will have to make if demand is as high or higher than projected, including the possible need to cap enrollment in a way that is equitable, meeting Robotics' and Engineering's commitment to diversity.

Curriculum and Degree Requirements

Below is a proposed set of course requirements for a Major in Robotics at the University of Michigan in accordance with the Core Requirements for Undergraduate Programs in the College of Engineering.

Michigan Robotics Undergraduate Program Requirements for Majors

Major Declaration Requirements

To declare a major in Robotics, a student must be a College of Engineering student and:

1. Have completed at least one full term at UM Ann Arbor
2. Have an overall UM GPA of 2.0 or better in courses taken at the UM Ann Arbor campus and be in good standing
3. Have completed or earned credit by exam or transfer for at least one course in each of these categories:
    a. Introductory Linear Algebra (e.g. Robotics 101 or Math 214)
    b. Introductory Calculus (e.g. Math 115, 116 or 156)
    c. Calculus-based physics lectures (e.g. Physics 140 or 160)
    d. Required introductory Engineering (~~Robotics 103 or~~ Engineering 100, and Robotics 102 or Engineering 101)
    e. Teamwork in Robotics: ROB 204* *Human-Robot Systems*

College of Engineering Core Program Requirements

1. Full Spectrum Robotics Introduction
    a. Introduction to Engineering: ROB 103 *Robotics Mechanisms* or Engineering 100

b. Computational Thinking: ROB 102 *Introduction to AI and Programming* or Engineering 101 or introductory programming equivalent)
c. Linear Algebra: ROB 101 *Computational Linear Algebra* or Math 214 or Math 217 or Math 417 or Math 419

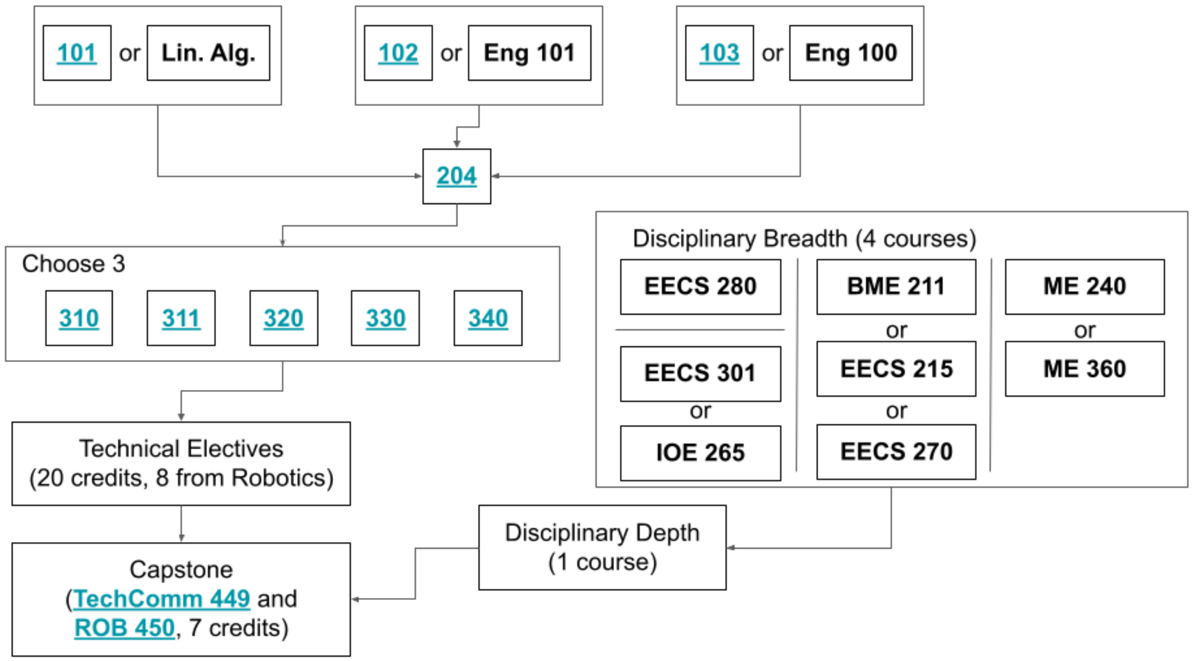
2. Calculus requirements
   a. Introductory Calculus:
      Math 115 or Math 120 (AP); and Math 116 or Math 121 (AP)
   b. Intermediate Calculus: Math 215 or Math 216
3. Physics 140/141 and Physics 240/241
4. Chemistry 130 and 125/126*
5. Intellectual Breadth (16 credits) (as specified by the College of Engineering Core Requirements Bulletin - https://bulletin.engin.umich.edu/ug-ed/reqs/#subnav-11)
6. General Electives (15 credits)
   a. 15 credits are "required"; CoE degrees require 128 total credits, and more or fewer GE credits may be needed to achieve this total depending on individual factors in a student's record.

Robotics in Engineering Program Requirements

1. Teamwork in Robotics: ROB 204 *Human-Robot Systems*
2. Robotics Core: at least three of the following courses:
   a. ROB 310 *Robot Sensors and Signals*
   b. ROB 311 *Build Robots and Make Them Move*
   c. ROB 320 *Robot Operating Systems*
   d. ROB 330 *Localization, Mapping, and Navigation*
   e. ROB 340 *Human-Robot Interaction*
3. Discipline Breadth: at least one approved course from all of the following areas:
   a. Data Structures and Programming: EECS 280
   b. Probability, Statistics, and Visualization: IOE 265 or EECS 301
   c. Electronics and Circuits: EECS 215 or EECS 270 or BME 211
   d. Kinematics and Dynamics: ME 240 or ME 360
   e. Technical Communications: TCHNCLCM 340*
      Technical Communication for Project Teams in Robotics
4. Discipline Depth: one course from the following list (or approved by the Robotics Undergraduate Committee), such as IOE 333, AERO 201, EECS 373, NAME 270, EECS 281, EECS 370, EECS 216, EECS 351, MSE 220
5. Technical Electives: a minimum of 20 credit hours, with a minimum 8 credit hours from the approved list of Upper Level Robotics Courses and 300-level courses not counted for the Robotics Core requirement
6. Major Design: ROB 450* *Robotics Capstone* and
   TCHNCLCM 449* *Advanced Technical Communication for Robotics*

* to be developed and approved as part of the Robotics Capstone experience

a. Robotics Major Curricular Graph



b. Sample Course Schedule for a Major in Robotics

This sample course schedule has in mind a Robotics Major that is oriented towards computing and autonomous robots. Similar sample course schedules can be realized for Robotics Majors oriented towards mechanical systems, electrical systems, aerial robotics, autonomous underwater systems, human factors, project management, and more.

	Credit Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Subjects required by all programs	(55 hours)								
Robotics 101 or Math 214[1]	4	**4**							
Engineering 100 or Robotics 103	4	**4**							
Engineering 101 or Robotics 102	4		**4**						
Mathematics 115 and 116	8		**4**	**4**					

[1] Or satisfying linear algebra course

Mathematics 215 or 216	4				**4**				
Physics 140 and Lab 141	5				**5**				
Physics 240 and Lab 241	5						**5**		
Chemistry 125/126/130 or 210/211	5							**5**	
Intellectual Breadth	16	**4**	**4**	**4**		**4**			
Program Subjects	(16 hours)								
Robotics 204	4		**4**						
Robotics 310	4								
Robotics 311	4						**4**		
Robotics 320	4				**4**				
Robotics 330	4					**4**			
Robotics 340	4								
Disciplinary Breadth	(16 hours)								
EECS 280 - Data Structures	4			**4**					
IOE 265 - Probability and Stat	3					**3**			
EECS 215 or 270 or BME 211	4			**4**					
ME 240 or 360	4					**4**			
TCHNCLCM 340*	1					**1**			
Disciplinary Depth	(4 hours)								
EECS 281	4				**4**				
Major Design Experience	(6 hours)								
Robotics 450 or EECS 467	4								**4**
TechComm 495*	2								**2**
Technical Electives	(20 hours)								
Upper Level Robotics Electives	12						**4**	**4**	**4**

Flexible Technical Electives	10						**3**	**4**	**3**
General Electives	(9 hours)	**3**						**3**	**3**
Total	128	**15**	**16**	**16**	**17**	**16**	**16**	**16**	**16**

c. List to be Approved Upper Level Robotics Courses

Upper Level Electives	
Signals and Sensors	
ROB 410	*Advanced Sensors*
ROB 412	*Neurorobotics*
Actuation and Motion	
ROB 411	*Robot Controls*
ROB 413	*Legged Locomotion*
ROB 415	*Multi-Robot Systems*
ROB 416	*Robot Dynamics and Simulation*
Reasoning and Autonomy	
ROB 420	*Mobile Manipulation and Semantic Robotics*
ROB 421	*Optimal Robotics*
ROB 422	*Algorithmic Robotics*
ROB 423	*Autonomous Vehicles*
Perception and Learning	
ROB 430	*Probabilistic Robotics*
ROB 431	*Robot Learning*
ROB 432	*3D Robot Perception*
Users and Interaction	
ROB 440	*Human-Robot Collab*
ROB 441	*Physical HRI*
ROB 442	*Ethics AI & Robotics*
Robustness and Exploration	
ROB 470	*Experimental UAS*
ROB 471	*Marine Robotics*
ROB 472	*Space Robotics*

Projects and Design	
ROB 413	*Bioinspired Robotics*
ROB 464	*Hands-on Robotics*
Capstone	
TCHNCLCM 449	*Requirements Engin*
ROB 450	*Robotics Capstone*

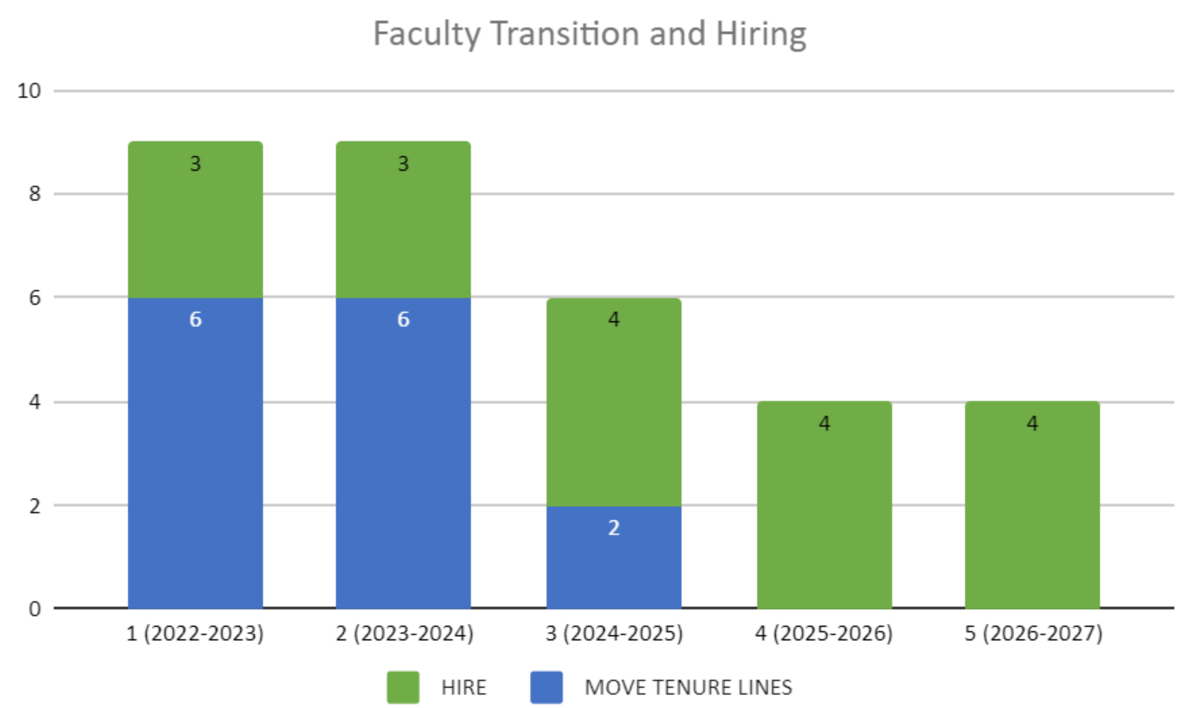
Faculty Resources

The Michigan Robotics Institute currently comprises an interdisciplinary group of 27 core faculty that span 12 departments, coupled with 42 affiliate faculty that contribute to the breadth and excellence of research. Robotics faculty research expenditures continue to show significant growth, outpacing the addition of new faculty. Indeed, over the past five years, research expenditures have increased from $5.6M to $16.0M, nearly tripling despite the addition of only five faculty members (~20% new faculty). The Institute emphasizes 'Full Spectrum Robotics,' with a broad array of faculty research interests, including human-robot interaction, legged and rehab robotics, artificial intelligence, autonomous and connected vehicles, dexterous manipulation, among many other areas.

The Institute offers a Graduate Program in Robotics with both MS and PhD degrees. Graduate students first matriculated in Fall 2014, and the program currently includes 158 students (87 MS and 71 PhD). Since its inception, applications have risen to over 1,000 in 2020. Michigan Robotics is currently engaged in the development of an undergraduate program and *Robotics Pathways for Undergraduates* curricular model that would lead to a major in robotics.

When (if) the Robotics Department is launched, there will be somewhere between 12 and 15 CoE T/TT faculty who will transfer tenure to the new department and we have two lecturers. The existing departments are insisting that the faculty transition in a phased manner. In addition, the College will provide hiring slots.

The table below shows the planned transitions of tenure slots and the hiring of new faculty. We may need to call on transferring faculty to teach Robotics UG courses before they transfer tenure and all of their research dollars to Robotics. This is under negotiation with the Office of the ADAA. Input from the CoE Curriculum Committee is welcome.



Admissions Requirements and Projected Enrollment

Enrollment: Market analysis and surveys contained in the “Proposal to Create a Robotics Department in the College of Engineering” suggest an undergraduate enrollment of 435 as the lower end. These sources all point toward a very high degree of student interest. In fact, as many as 40 percent of current students who responded to the survey expressed interest in a Michigan Robotics major or minor, while 25 percent of respondents who enrolled elsewhere indicated that they might have decided differently if Michigan currently offered these degree programs. Based on a conservative interpretation of these results, we estimate that 10% of incoming freshmen will declare Robotics. Assuming no attrition, no incoming transfers, and 4-year graduation rates, the department will enroll 435 ugrads in steady state. Of course, this enrollment level needs to be achieved over time. Figure 1.1.1. shows the proposed enrollment in the initial five-year ramp-up period.

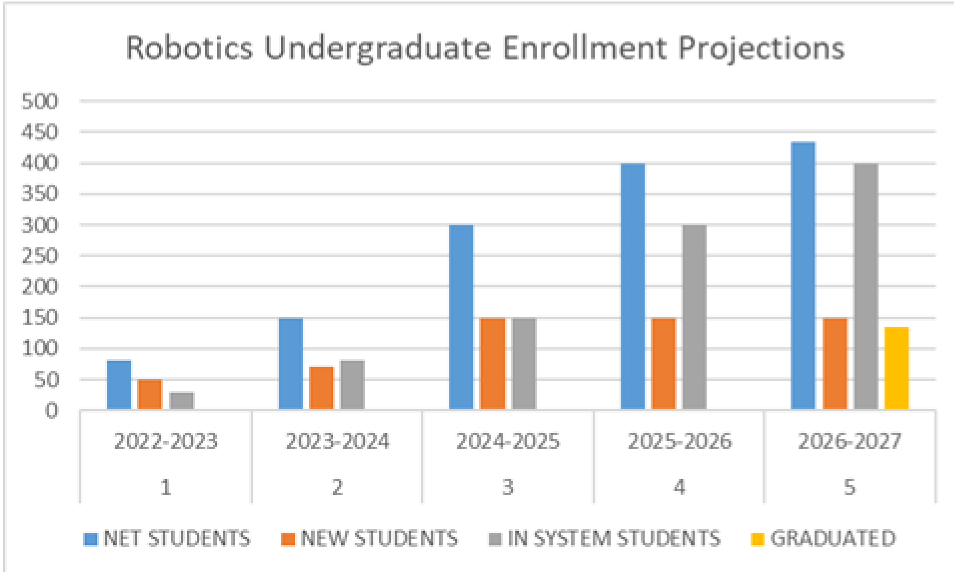


Figure 1.1.1.: Bar chart showing the proposed ramp-up of undergraduate student enrollment. Net students is the sum of new and in-system students less the number of graduated students.

Undergraduate Enrollment Control Mechanism The higher-end prediction potential majors cited in the market analysis would overwhelm the new department. Therefore, the Robotics department is aware that it must work with the Office of the ADUE to develop a fair and equitable mechanism to limit the enrollment in the initial five year period. When Biomedical Engineering first became a department, it limited its undergraduate enrollment by imposing a minimum GPA for declaring students. However, it is well-known that GPA is not necessarily an objective measure of academic success and is instead strongly correlated with demographic and socioeconomic factors. This is in direct contradiction with the goal of the new department to reform academic norms and culture. Another approach to limit the number of students is by creating a holistic review process to declare. No process currently exists for this at the department level, and such a process could be time-consuming for the fledgling department. A less onerous process, but one that may be less satisfying for students, would be a lottery system. Either of these processes, and perhaps others, should be considered carefully prior to implementation.

Admissions Requirements: These were given earlier in the document: **Major Declaration Requirements**

Program Assessment

Six-year Undergraduate Program Review

In concert with the planned Robotics Department, the Robotics Undergraduate Program is proposed to be reviewed every six years. This program review will consist of an internal review and an external review, each of which will produce evaluation reports that are submitted to the College of Engineering. The internal review will be done by a committee of selected faculty to summarize the current state of the Robotics Undergraduate Program and evaluate its strengths, weaknesses, and opportunities. This internal review will be followed by an external review performed by esteemed individuals in the field of robotics. It is expected that at least one member of this committee will also be a member of our standing Diversity Advisory Board. The report generated from this external review will be submitted to the College of Engineering.

Diversity Advisory Board

We wish to propose a group of highly distinguished, accomplished, and committed individuals from academe, industry, and a government lab to meet with us annually. Their combined expertise will serve us well for constructing and evolving a curriculum that is inclusive, fair, technically sound, meets the needs of professional practice as well as leading graduate programs, and could potentially be adopted by other departments and universities. *We have included the CoE Associate Dean of Undergraduate Education to provide advice for socializing our ideas at the 100-level with all of engineering at Michigan*.

Nancy M. Amato, Abel Bliss Professor and Head, Department of Computer Science, University of Illinois, Urbana-Champaign. *Role*: Providing advice on inclusive practices for women and minorities in STEM. Assessing adoption for UIUC.

Susan M. Lord, Professor and Chair of Integrated Engineering, Professor of EE, University of San Diego. *Role*: Providing expert advice on gender and diversity in engineering and how to operate a highly successful NSF RED proposal.

Monica Anderson, Associate Professor of Computer Science, University of Alabama, Researcher in Robotics. *Role*: Providing advice, best practices and effectiveness for mentoring of underrepresented minorities and women in robotics and computer science. She will bring her expertise for broadening participation from her work on the leadership of the NSF BPC-funded Institute for African-American Mentoring in Computing Sciences iAAMCS that serves as a national resource for all African-American computer science students and faculty.

Melanie Moses, Professor, Department of Computer Science, Secondary Appointment, Department of Biology, University of New Mexico. External Faculty member of the Santa Fe Institute. *Role*: Providing insights into effective methods for challenge problems and engagement strategies to reach underrepresented groups. She will bring her expertise from founding highly influential broadening participation programs, as **the** originator of CSforAll, which is now a national movement, and the NASA Swarmathon, a multi-robot exploration competition that has had spirited participation from tribal colleges and Minority Serving Institutions.

Craig Stephens, PhD, Director: Controls & Automated Systems, Ford Motor Company. *Role*: Preparing students to enter the Robotics-AI workforce with a BSE degree in robotics. He will build on Michigan's unique Public-Private relationship that provides Ford an on-campus site for direct collaboration with Michigan faculty.

Michael Wolf, PhD, Principal Robotics Technologist and Group Supervisor, Maritime & Multi-Agent Autonomy, JPL. *Role*: Preparing students to enter the Robotics-AI workforce with a BSE degree in robotics.

Joanna Millunchick, Associate Dean for Undergraduate Education, Professor Materials Science and Engineering, Arthur F. Thurnau Professor, Bicentennial Professor, Academic Director of MSTEM Engineering Academy, College of Engineering, University of Michigan. *Role*: Leading the revision of calculus to combine Math 115 (Calc I) and Math 116 (Calc II) into a single course (she commissioned the report). Advocating for dissemination of our first-semester math course throughout the College of Engineering or the flexibility to choose among a set of courses to meet the math requirements.

Longitudinal Student Surveys

The Robotics Undergraduate Program firmly believes that wise student feedback comes longitudinally with time and perspective. As such, we will conduct annual surveys of the group of individuals that have enrolled in a Michigan Robotics course at any period of time. In addition to current students and dedicated roboticists, this group surveyed includes alumni, students that may have considered robotics but took a different path, and engineering students whose studies overlap with the Robotics. These surveys will be designed to gather information about student satisfaction, ideas for potential improvements and innovations, and program effectiveness in the professional outcomes longitudinally.

Accreditation

The Robotics Undergraduate Program is not planning in the short term to become accredited by bodies such as the Accreditation Board for Engineering and Technology, Inc. It is expected that the Robotics Undergraduate Program will lead in the formation of robotics as an academic discipline. As such, Michigan Robotics is planning to lead in the definition of standards for accreditation of robotics academic programs as the discipline takes shape over time.

Mitigation Plans and Responsibility for Program Deletion

The proposed degree program will go hand and hand with the creation of the new department. We are unaware of existing guidelines for the deletion of a department, which we believe, is the unique path leading to deletion of the proposed undergraduate major. If our assumptions are false, we will work with you on creating a plan for shutting down the degree.

We would be happy to have a sunset clause.

Requirements for Funding, Space, and Equipment

Funding and Equipment: The parameters to build a complete budget for the new department, a major in Robotics, equipment for labs, and a model for attributing GSIs and IAs that is more generous than the existing one in CoE, are included in the “Proposal to Create a Robotics Department in the College of Engineering”. If the CoE Curriculum Committee has concerns over budget matters, we suggest working with the office of Deborah Mero and RPM https://rpm.engin.umich.edu/finance-budget/.

Space: The Ford Motor Company Robotics Building is a four-story, $75 million, 134,000-square-foot complex situated on North Campus. Its first three floors hold custom U-M research labs for robots that fly, walk, roll and augment the human body—as well as classrooms, offices and makerspaces. Through a unique agreement, the fourth floor houses Ford’s first robotics and mobility research lab on a university campus, as well as 100 Ford researchers and engineers.

FRB Research Lab Space (as of 06/02/21)

- 23,647 sq ft
- Assigned PI’s: 19, though two seem to be on semi-permanent leave
- Could support an additional ~7 to 9 PI’s (given a 750 sq ft average per PI).

FRB Instructional Labs
There are 2 adjacent instructional labs (FMCRB 2010 + 2020) with a capacity of 32 students each (total of 64 students). In the Maker Space, the Student Team area is being configured to support 24 students per lab section.

We will be short on lab space for the new degree program. The 56 seat classroom FMCRB 1050 is directly across the hallway from the Robotics Institute’s Electronics Laboratory. We will seek to schedule the lab sessions for ROB 310 Robot Electronics in FMCRB 1050, and wheel in carts with electronics equipment as needed. When soldering needs to be done, students can use the 6 snorkels in the Electronics Laboratory. Otherwise, the furniture in the room is fine for a lab experience.

Joanna M. Millunchick • Associate Dean for Undergraduate Education

September 2, 2021

Dear College of Engineering Curriculum Committee,

I strongly endorse the planned undergraduate major in Robotics proposed by the Robotics Institute. In my capacity as Associate Dean for Undergraduate Education, I followed Robotics' progress in designing innovative first year courses. The approach that Robotics uses is to center student engagement so that they may apply theory to practice very directly. Also, they intentionally chose topics that are accessible to students regardless of their background, thus enhancing inclusivity.

I chaired the Robotics Planning Committee since January 2021 that submitted a master plan for the design and launch of a successful Robotics Department to Dean Alec Gallimore and Associate Dean for Academic Affairs, Steve Ceccio.

The proposal for an undergraduate degree in Robotics submitted by the Robotics Institute meets the high standards established by our existing departments. I strongly believe that the College has a unique opportunity to not only lead in Robotics research, but also to define the very discipline of Robotics itself.

Sincerely,

Joanna M. Millunchick
Associate Dean for Undergraduate Education

Robert H. Lurie Engineering Center OFFICE: (734) 647-7150 1221 Beal Avenue aduemillunchick@umich.edu Ann Arbor, Michigan 48109-2102

Course Approval Request Form

Office of the Registrar, University of Michigan

1210 LSA Building
500 S. State Street
Ann Arbor, MI 48109-1382
Phone: 734.763.2113
Fax: 734.936.3148
ro.curriculum@umich.edu
ro.umich.edu

☑ CHECK APPROPRIATE BOXES FOR ALL CHANGES

Action Requested
- ☑ New Course
- ☐ Modification of Existing Course
- ☐ Deletion of Existing Course

Date of Submission: 2021-10-14
Effective Term: Winter 2023

☑	Course Offered ☑ Indefinitely ☐ One term only	**RO USE ONLY** Date Received: Date Completed: Completed By:

	CURRENT LISTING			**REQUESTED LISTING**		
☑	Dept (Home): Subject: Catalog:			Dept (Home): Robotics Subject: ROB Catalog: 310		
☐	☐ Course is Cross-Listed with Other Departments			☐ Course is Cross-Listed with Other Departments		
	Department	Subject	Catalog Number	Department	Subject	Catalog Number
☑	Course Title (full title)			Course Title (full title) Robot Sensors and Signals		
☑	Abbreviated Title (20 char)			Abbreviated Title (20 char) Sensors & Signals		
☑	Course Description (Please limit to 50 words and attach separate sheet if necessary) Covers practical analog and digital electronics for robotics. Students will: prototype, test, and debug various analog and digital circuits; interface a microcontroller to external circuits; learn to design and prototype circuit boards; interpret data recorded from physical circuits. An exploration of circuits and embedded systems that supports integrated robotic design.					
☑	Full Term Credit Hours Undergraduate Min: 4 Undergraduate Max: 4	Graduate Min: Graduate Max:		Half Term Credit Hours Undergraduate Min: Undergraduate Max:	Graduate Min: Graduate Max:	
☑	Course Credit Type Undergraduate Student					
☑	Repeatability ☐ Course is Repeatable for Credit Maximum number of repeatable credits: 0			☐ Course is Y graded ☐ Can be taken more than once in the same term		

Subject: Catalog:	
☑	Grading Basis ☑ Graded (A – E) ☐ Credit/No Credit ☐ Satisfactory/Unsatisfactory ☐ Pass/Fail ☐ Business Administration Grading ☐ Not for Credit ☐ Not for Degree Credit ☐ Degree Credit Only Add Consent ☐ Department Consent ☐ Instructor Consent ☑ No Consent Drop Consent ☐ Department Consent ☐ Instructor Consent ☑ No Consent

	CURRENT LISTING	REQUESTED LISTING
☑	Advisory Prerequisite (254 char)	Advisory Prerequisite (254 char) ROB 101 (Computational Linear Algebra) ROB 103 (Robotic Mechanisms)
☑	Enforced Prerequisite (254 char) Minimum grade requirement:	Enforced Prerequisite (254 char) ROB 204 and (EECS 215 or BME 211) Minimum grade requirement: C-
☐	Credit Exclusions	Credit Exclusions

	Course Components	Graded Component	Terms Typically Offered
☑	☑ Lecture	☐	☐ Fall
	☐ Seminar	☐	☑ Winter
	☐ Recitation	☐	☐ Spring
	☑ Lab	☑	☐ Summer
	☐ Discussion	☐	☐ Spring/Summer
	☐ Independent Study	☐	

Cognizant Faculty Member Name: Peter Gaskell | Cognizant Faculty Member Title: Lecturer IV

SIGNATURES ARE REQUIRED FROM ALL DEPARTMENTS INVOLVED (Please Print AND Sign Name)

Contact Person: Christina Hollis   Email: crhollis@umich.edu   Phone: 734-763-2869

CoE Curriculum Committee Representative: Print: Date:

CoE Curriculum Committee Chair: Print: Date:

Home Department Chair: Jessy Grizzle Print: Jessy Grizzle Date: 10-14-2021

Cross-Listed Department Chair: Print: Date:

Cross-Listed Department Chair: Print: Date:

Cross-Listed Department Chair: Print: Date:

DEPARTMENTAL/COLLEGE USE ONLY

Current:	**Requested:**
Course Description	Course Description Covers practical analog and digital electronics for robotics. Students will: prototype, test, and debug various analog and digital circuits; interface a microcontroller to external circuits; learn to design and prototype circuit boards; interpret data recorded from physical circuits. An exploration of circuits and embedded systems that supports integrated robotic design.
Class Length	Class Length Full term
Contact hours (lecture):	Contact hours (lecture): 2
Contact hours (recitation)	Contact hours (recitation) 0
Contact hours (lab)	Contact hours (lab) 4

Additional Info:

Submitted by:
Home dept

Describe how this course fits with the degree requirements:
Elective course for Robotics majors interested in physical construction of robots.

Special resources of facilities required for this course:
Availability of a CAEN Lab
Lab space to perform electronic measurements
Workshop space to build electronics

Supporting statement:
Assessment:
50% — 10 short group lab reports: filling in tables, plotting data, and answering questions about the results. This is done mostly in the lab and is due before the next week's lab session, should not be much out of lab work other than maybe formatting and labeling axes.

20% — 4 short individual quizzes or homeworks each covering 2 weeks worth of lab material. The final 2 weeks of lab projects are more building stuff, so not much knowledge that is testable in quiz format.

5% — Final group project proposal: this is where we grade the planning aspects of the group project and the thoughtfulness of the ideas

20% — Final group project presentation, this will be a demo of the circuit and poster presentation

5% — participation

Schedule (14 weeks total)

Week	Topics
Week 1	voltage, current, & power Kirchoff's law RLC circuits in time domain
Week 2	Impedance RLC circuits in frequency domain
Week 3	Op Amps Gain Feedback
Week 4	PN Junctions Diodes LEDs Photovoltaics
Week 5	Transistors Transistor amplifiers Voltage regulators Power supplies Batteries
Week 6	Survey of sensors AVR/ARM microcontrollers
Week 7	Binary / Hexadecimal Boolean Logic Logic gates
Week 8	Flip-flops Higher level logic (counters, adders, registers, multiplexers)
Week 9	Analog vs. Digital signal representation Analog to Digital conversion
Week 10	Serial communication RF communication
Week 11	Printed circuit board technologies CAD/CAM for electronic circuits
Week 12	Datasheet literacy Soldering Practical electronic components

Week 13	Societal impacts of sensors and systems, including issues of privacy, bias in data collection/mining, equitability of access
Week 14	Wrap-up Project presentations

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Labs:

LAB 1: Resistors, Voltage & Current
Equipment: Power Supply, DMM, Breadboard

LAB 2: Time & Frequency response of various RLC circuits:
Equipment: Function generator, Oscilloscope, Breadboard
Students will place components on a breadboard and for each circuit:
1. measure the time constant by driving the circuit with a square wave
2. manually sweep a function generator while measuring the peak voltage of a sine wave on an oscilloscope
3. log all data in a log book.
4. plot the data for the lab report
5. answer questions based on the material.

LAB 3: Op amps, Noise, Active Filters, Differential signals:
active summing (add noise module signal to AC signal)
active filter (Sallen-Key topology)
current sense differential amplifier
3 op amp instrumentation amp
noise rejection and wheatstone bridge

LAB 4: Diodes & Photosensors & FET Amplifiers:
Students will place components on a breadboard and apply signals while making electrical measurements and logging the data in a log book. They will plot the data for the lab report and answer questions based on the material.
1. voltage drop of Diodes / LEDs
2. FET inverting amplifier
3. Measure brightness of LED with Photovoltaic or Photodiode

LAB 5: Microprocessor, ADC & DAC
toggle LED with I/O pin, charlieplexing
measure an analog voltage and print to terminal
1 bit DAC with PWM and RC filter
pseudo RMS measurement of AC waveform with rectifier/filter

LAB 6: Logic Gates, Flip-flops, Schmitt trigger

AND, OR, INV, and XOR from NAND gates
3-Bit adder with logic gates

LAB 7: Quadrature decoder to counter with FFs

LAB 8: Serial communication
Parallel ADC + Shift register + clock -> microcontroller
Interface to a digital sensor to capture data…

LAB 9: RF Communications
Interface to NRF24L01 module
Measure transmission distance

LAB 10: PCB Design/Solder/Build lab
create a simple circuit schematic and layout on a PCB
Mill it on the PCB mill
Solder it
Test it works

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Date of Submission: 2021-10-14
Effective Term: Fall 2022

☑	Course Offered ☑ Indefinitely ☐ One term only	**RO USE ONLY** Date Received: Date Completed: Completed By:

	CURRENT LISTING			REQUESTED LISTING		
☑	Dept (Home): Subject: Catalog:			Dept (Home): Robotics Subject: ROB Catalog: 311		
☐	☐ Course is Cross-Listed with Other Departments			☐ Course is Cross-Listed with Other Departments		
	Department	Subject	Catalog Number	Department	Subject	Catalog Number
☑	Course Title (full title)			Course Title (full title) How to Build Robots and Make Them Move		
☑	Abbreviated Title (20 char)			Abbreviated Title (20 char) How to Make Robots		
☑	Course Description (Please limit to 50 words and attach separate sheet if necessary) ROB311 introduces the fundamentals of mechanical design, control, fabrication, actuation, instrumentation, and computer interfaces required to realize robotic systems. Students will learn to analyze/simulate rigid body kinematics, kinetics, and dynamics, as well as assess the impedance properties of their designs. 'Hands-on' skills will be emphasized in addition to theoretical concepts.					
☑	Full Term Credit Hours Undergraduate Min: 4 Undergraduate Max: 4	Graduate Min: Graduate Max:		Half Term Credit Hours Undergraduate Min: Undergraduate Max:	Graduate Min: Graduate Max:	
☑	Course Credit Type Undergraduate Student					
☑	Repeatability ☐ Course is Repeatable for Credit Maximum number of repeatable credits: 0			☐ Course is Y graded ☐ Can be taken more than once in the same term		

Subject: Catalog:	
☑	Grading Basis ☑ Graded (A – E) ☐ Credit/No Credit ☐ Satisfactory/Unsatisfactory ☐ Pass/Fail ☐ Business Administration Grading ☐ Not for Credit ☐ Not for Degree Credit ☐ Degree Credit Only Add Consent ☐ Department Consent ☐ Instructor Consent ☑ No Consent Drop Consent ☐ Department Consent ☐ Instructor Consent ☑ No Consent

	CURRENT LISTING	REQUESTED LISTING
☑	Advisory Prerequisite (254 char)	Advisory Prerequisite (254 char) ME 240 and/or 360, ROB 310
☑	Enforced Prerequisite (254 char) Minimum grade requirement:	Enforced Prerequisite (254 char) ROB 204 Minimum grade requirement: C-
☑	Credit Exclusions	Credit Exclusions None

	Course Components	Graded Component	Terms Typically Offered
☑	☑ Lecture	☐	☑ Fall
	☐ Seminar	☐	☐ Winter
	☐ Recitation	☐	☐ Spring
	☑ Lab	☑	☐ Summer
	☐ Discussion	☐	☐ Spring/Summer
	☐ Independent Study	☐	

Cognizant Faculty Member Name: Elliott Rouse | Cognizant Faculty Member Title: Assistant Professor

SIGNATURES ARE REQUIRED FROM ALL DEPARTMENTS INVOLVED (Please Print AND Sign Name)

Contact Person: Christina Hollis   Email: crhollis@umich.edu   Phone: 734-763-2869

CoE Curriculum Committee Representative: Print: Date:

CoE Curriculum Committee Chair: Print: Date:

Home Department Chair: Print: Jessy Grizzle Date: 10/14/2021

Cross-Listed Department Chair: Print: Date:

Cross-Listed Department Chair: Print: Date:

Cross-Listed Department Chair: Print: Date:

DEPARTMENTAL/COLLEGE USE ONLY

Current:	**Requested:**
Course Description	Course Description ROB311 introduces the fundamentals of mechanical design, control, fabrication, actuation, instrumentation, and computer interfaces required to realize robotic systems. Students will learn to analyze/simulate rigid body kinematics, kinetics, and dynamics, as well as assess the impedance properties of their designs. 'Hands-on' skills will be emphasized in addition to theoretical concepts.
Class Length	Class Length Full term
Contact hours (lecture):	Contact hours (lecture):
Contact hours (recitation)	Contact hours (recitation) 0
Contact hours (lab)	Contact hours (lab) 3

Additional Info:

Submitted by:
Home dept

Describe how this course fits with the degree requirements:
The objective of Robotics 311 is to introduce emerging roboticists to the tools that enable rapid design, prototyping, and control of robotic systems; in addition, the overarching goal of the course is conveniently obtained from the course title: "How to build robots and make them move." The course material will be delivered in a lecture setting, with one lecture per week dedicated to group projects. The goal of the projects will be to showcase the lecture content (e.g. the sensing, acting, and reasoning sections of the lecture material).

The course is intended to combine theory and practice. The lecture components of the class will include theoretical contributions in modeling, Lagrangian & Newton-Euler dynamics, and control, while the practical components will focus on CAD, manufacturing, and electrical hardware. Robotics 311 is arranged in this way to show how the theoretical and practical combined can create opportunities greater than the sum of their parts. Following the completion of this course, students should be able to:

Recognize a challenge that could be solved with a robotic system
Design a robotic system to solve the challenge
Manufacturer the robotic system
Test the robotic system for completion of the task
Lecture components will be taught broadly (tools to solve broad problems), where more 'application-specific' questions will be addressed with individual groups / group projects.

Special resources of facilities required for this course:

If there are any additional special resources or facilities required for this course, enter them here.

Ideally, this course would have the 'hands on' lecture in the large lecture hall in 1st floor FRB.

<u>Supporting statement:</u>
This course provides an important contribution to the students that will graduate with an undergraduate degree from U-M Robotics; namely, the tools to interact with the physical world. In addition to being well trained in the theoretical and computational aspects of Robotics, this course ensures our students have the pathway to also learn how that theoretical understanding can be used to impact the world around them. Robotics 311 is a key component of our Y2 - Y3 'Robotics Threads,' where students have the ability to curate the type of roboticist they want to be. Courses in the Robotics Threads range from electronics and robot building to perception and human-robot interaction. Since students take a minimum of three, they are able to semi-specialize in an area of robotics.

Assessment: Robotics 311 will use several mechanisms to gauge students' knowledge. The course will have ~7 technical homework assignments (i.e. paper and pencil style problems), in addition to a midterm exam. The student projects will be used in lieu of a final exam. Students will be graded on the ability of their project to complete the objective(s) set forth in the beginning of the term during project selection. Projects will be graded during demonstration / presentations that occur during the last two lecture periods. Our approach to assessment is based on the course's objectives of teaching a combination of hands-on skill and theoretical skills.

Schedule (14 weeks total)

	Topics	Notes	Activities
Week 1	• Course overview • Basic effort and flow review • Rigid body dynamics • Lagrangian / Newton-Euler	Introduction Intro to modeling systems	Form groups and select group projects.
Week 2	• Rigid body dynamics cont. • Forward and inverse dynamics	Intro to modeling systems	Analyze system from group project
Week 3	• Brushed motors • Torque-speed / current-voltage • Basic brushless motor overview	Actuation	Determine actuation method for group project and simulate
Week 4	• Pneumatic systems • Basic transmission types and equations • Efficiency & thermal analysis	Actuation	Determine desired transmission ratio
Week 5	• Power supply considerations • PWM • Regeneration • CAD intro	Actuation	Begin sketching design concepts
Week 6	• Basic Solidworks • 3D Printers • Laser cutters	Rapid prototyping	Begin designing project parts
Week 7	• Solidworks cont. • Shopbots • Waterjet • Vinyl cutter	Rapid prototyping	Design project to be manufactured using two RP methods
Week 8	• Basic closed loop control • Block diagrams • PID control	Control	Manufacture project prototypes

Week 9	• Impulse response • Frequency response • Bandwidth	Control	Create plan for control of project
Week 10	• Impedance • Transfer functions • Matching / reflected inertia	Control	Implement control using microcomputer
Week 11	• Sensors • Data acquisition	Sensing and Comms	Implement sensing
Week 12	• Analog communication • Digital communication • Software drivers	Sensing and Comms	Debugging and comms
Week 13	• Ethics in robotics • Societal impact • Project work week	Robo-ethics	Testing and preparation for demo
Week 14	• Wrap-up • Project presentations	Presentations	Final project presentations and demos

Course Approval Request Form

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☑ CHECK APPROPRIATE BOXES FOR ALL CHANGES

Action Requested
- ☑ New Course
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- ☐ Deletion of Existing Course

Date of Submission: 2021-11-18
Effective Term: Fall 2022

☑	Course Offered ☑ Indefinitely ☐ One term only	**RO USE ONLY** Date Received: Date Completed: Completed By:

	CURRENT LISTING			**REQUESTED LISTING**		
☑	Dept (Home): Subject: Catalog:			Dept (Home): Robotics Subject: ROB Catalog: 330		
☐	☐ Course is Cross-Listed with Other Departments			☐ Course is Cross-Listed with Other Departments		
	Department	Subject	Catalog Number	Department	Subject	Catalog Number
☑	Course Title (full title)			Course Title (full title) Localization, Mapping, and Navigation		
☑	Abbreviated Title (20 char)			Abbreviated Title (20 char) SLAM & Navigation		
☑	Course Description (Please limit to 50 words and attach separate sheet if necessary) The development of full-stack autonomous navigation and semantic mapping for mobile robots. Topics include dead reckoning from odometry, sensor modeling of LIDAR and IMUs, simultaneous localization and mapping, semantic scene understanding, and an introduction to deep learning methods for convolutional feature learning and object detection.					
☑	Full Term Credit Hours Undergraduate Min: 4 Undergraduate Max: 4	Graduate Min: Graduate Max:		Half Term Credit Hours Undergraduate Min: Undergraduate Max:	Graduate Min: Graduate Max:	
☑	Course Credit Type Undergraduate Student					
☑	Repeatability ☐ Course is Repeatable for Credit Maximum number of repeatable credits: 0			☐ Course is Y graded ☐ Can be taken more than once in the same term		

Subject: Catalog:		
☑	Grading Basis ☑ Graded (A – E) ☐ Credit/No Credit ☐ Satisfactory/Unsatisfactory ☐ Pass/Fail ☐ Business Administration Grading ☐ Not for Credit ☐ Not for Degree Credit ☐ Degree Credit Only	Add Consent ☐ Department Consent ☐ Instructor Consent ☑ No Consent Drop Consent ☐ Department Consent ☐ Instructor Consent ☑ No Consent

	CURRENT LISTING	REQUESTED LISTING
☑	Advisory Prerequisite (254 char)	Advisory Prerequisite (254 char) (IOE 265 or EECS 301) and (ME 240 or ME 360) and (Math 215 or Math 216)
☑	Enforced Prerequisite (254 char) Minimum grade requirement:	Enforced Prerequisite (254 char) ROB 204, EECS 280 Minimum grade requirement: C-
☐	Credit Exclusions	Credit Exclusions
☑	Course Components / Graded Component ☑ Lecture ☑ ☐ Seminar ☐ ☐ Recitation ☐ ☑ Lab ☐ ☐ Discussion ☐ ☐ Independent Study ☐	Terms Typically Offered ☑ Fall ☐ Winter ☐ Spring ☐ Summer ☐ Spring/Summer
Cognizant Faculty Member Name: Katie Skinner		Cognizant Faculty Member Title: Assistant Professor

SIGNATURES ARE REQUIRED FROM ALL DEPARTMENTS INVOLVED (Please Print AND Sign Name)

Contact Person: Christina Hollis Email: crhollis@umich.edu Phone: 734-763-2869

CoE Curriculum Committee Representative: Print: Date:

CoE Curriculum Committee Chair: Print: Date:

Home Department Chair: Jessy Grizzle Print: Jessy Grizzle Date: 11-18-2021

Cross-Listed Department Chair: Print: Date:

Cross-Listed Department Chair: Print: Date:

Cross-Listed Department Chair: Print: Date:

DEPARTMENTAL/COLLEGE USE ONLY

Current:	Requested:
Course Description	Course Description The development of full-stack autonomous navigation and semantic mapping for mobile robots. Topics include dead reckoning from odometry, sensor modeling of LIDAR and IMUs, simultaneous localization and mapping, semantic scene understanding, and an introduction to deep learning methods for convolutional feature learning and object detection.
Class Length	Class Length Full term
Contact hours (lecture):	Contact hours (lecture): 3
Contact hours (recitation)	Contact hours (recitation) 0
Contact hours (lab)	Contact hours (lab) 2

Additional Info:

Submitted by:
Home dept

Describe how this course fits with the degree requirements:
The objective of Robotics 330 is to introduce methods for the development of semantic autonomous navigation systems in current autonomous systems such as drones, self-driving cars, planetary rovers, and autonomous surface vehicles. Perception involves understanding sensors and signal processing to provide measurements for high-level inference and algorithmic implementations. The students will become familiar with sensing pipelines, the knowledge behind information processing for robot perception, and modern tools to these ends.

Robotics 330 focuses on the development of algorithms to solve robot perception and navigation problems using real sensory data provided by cameras, LIDAR, IMUs, and encoders. The students will program these models and algorithms using widely-used programming languages in robotics, namely, Python, C++, and MATLAB/Julia.

ROB 330 will provide a sufficient introduction to state-of-the-art deep learning methods using convolutional neural networks for feature learning, image classification, object detection and semantic segmentation in images. These topics will be integrated into a full stack perception and autonomous navigation package such that students will see the outcome in a visually appealing manner.

Students who take ROB 330 will learn aspects of the C++ and Python programming languages as primary language and MATLAB/Julia as the secondary languages for project and lab components. Python is the most common language for research and development among computer vision, machine learning and AI, and robotics communities due to the availability of open-source libraries and ease of use. C++ and MATLAB/Julia are used today in many fields of engineering. C++ is a pervasive standard for software development in widespread use and real-time robotics software development. Julia is an emerging language suited to the needs of modern engineers and scientists. Julia is comparable to MATLAB and Python in its powerful capabilities for numerical computation and enables computational thought that can be readily translated to new languages. Students will apply their previous programming knowledge to robot perception problems while mastering scientific programming for solving real-world data and robotics problems.

Special resources of facilities required for this course:
Availability of a CAEN Lab and access to lab space for 2 hour weekly lab sessions.

Supporting statement:
Robotics 330 acts as a bridge between ROB 101, 102, 103, and 204 and 400-level courses in robotics. Students will gain a sufficient understanding of robotic sensing and perception systems and an introduction to learning-based methods for semantic scene understanding and navigation required in future steps of undergraduate and graduate degrees in robotics and artificial intelligence.

Students will be evaluated through individual take-home problem sets due every 2-3 weeks and a final take home project. There will be three in-lab group projects due every 4-6 weeks and will be cumulative throughout the semester, with each project building on the previous project. Group projects will be assessed through peer review. This will provide students with intermediate feedback for testing components of their full-stack autonomous navigation system. Grading will be broken down into roughly 60% for projects, 20% for problem sets, and 20% final take home project.

ROB 330 is filling a gap in the curriculum for the Robotics Undergraduate degree as none of the existing computer vision and machine learning courses are developed for embedded intelligent systems and semantic autonomous navigation in 3D environments. Students will integrate their knowledge of mathematics (ROB 101 and other math courses) with robot hardware (sensors) in ROB 103, and AI and programming, ROB 102, in a coherent robotic perception system that supports today’s autonomous system development.

Schedule (14 weeks total)

	Lecture Topics	Lab Activity	Objectives
Week 1	Introduction • Course overview • What is robot perception? • Why is it hard (not solved)? • Sensors for perception	• Robot basic knowledge • Setup steps • Safety instructions	**Introduction to robot perception.** Understanding the pipeline of data acquisition, signal processing, and inference using direct or indirect measurements.
Week 2	Rigid Motion Geometry • 2D and 3D rigid motion • Robot motion models • Cartesian coordinate frames • Robot position and orientation • Rotation matrices • Orthonormality and SO(3) group • Euler Angles • Rigid Motions and SE(3) group • Homogeneous 3D transforms • Composition of transforms	• Motor, encoder test • LCM	**Getting familiar with the 2D and 3D geometric space and rigid motion to model a robot motion.** Use sensors for dead reckoning.
Week 3	Odometry • Wheel Encoders • Inertial Measurement Units • Odometry • Differential drive kinematics • Actuators • PID control • Dead reckoning	• Setpoint challenge tutorial	
Week 4	Probabilistic Methods • Probability introduction • Graphical models • Bayesian inference	• Setpoint challenge practice	
Week 5	Mapping • Occupancy grids • Counting sensor model • Binary Bayesian Filtering	• Setpoint challenge materials due • Setpoint challenge trials	**Implement Robotic occupancy mapping.**

Week 6	Localization • Monte Carlo localization • Sequential Bayesian filtering • Nonparametric distributions • Particle filtering	• Escape challenge tutorial	**Implement robot localization using motion and 2D/3D sensors.** Understanding the meaning behind indirect and direct data processing.
Week 7	Planning • Frontier exploration • A-star algorithm	• Escape challenge practice	
Week 8	RGB Sensing • 2D sensing using cameras and projection model • Monocular vision • Scale ambiguity	• Escape challenge practice	
Week 9	3D Sensing • LIDAR point clouds • 3D sensing • Geometry, appearance, and semantic notions • Projective data association	• Escape challenge materials due • Escape challenge trials • Detection challenge tutorial	**Getting familiar with 2D and 3D sensing hardware and point cloud processing tools**. Derive models and perform sensor calibration.
Week 10	Deep Learning • Convolutional neural networks • Representation/Feature learning • Image classification	• Detection challenge practice	**Implement a CNN for feature learning and classification.** Revisit localization and use objects as landmarks.
Week 11	Object Detection • Semantic scene understanding • Object-level scene understanding and localization • Object detection	• Detection challenge practice	
Week 12	Semantic Segmentation • Deep learning for semantic segmentation • Semantic segmentation from imagery	• Detection challenge trials • Detection challenge materials due	

Week 13	Semantic Mapping • Semantic counting sensor model and Bayesian inference • Bayesian inference for semantic sensor model.	• Individual take home final project	
Week 14	• Wrap-up • State-of-the-art/future of robot perception	• Individual take home final project	

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Date of Submission: 2021-10-15
Effective Term: Fall 2022

☑	Course Offered ☑ Indefinitely ☐ One term only	**RO USE ONLY** Date Received: Date Completed: Completed By:

	CURRENT LISTING			**REQUESTED LISTING**		
☑	Dept (Home): Subject: Catalog:			Dept (Home): Robotics Subject: ROB Catalog: 340		
☐	☐ Course is Cross-Listed with Other Departments			☐ Course is Cross-Listed with Other Departments		
	Department	Subject	Catalog Number	Department	Subject	Catalog Number
☑	Course Title (full title)			Course Title (full title) Human-Robot Interaction		
☑	Abbreviated Title (20 char)			Abbreviated Title (20 char) Hum-Rob Int		
☑	Course Description (Please limit to 50 words and attach separate sheet if necessary) Covers psychophysics, modeling a human operator within a control loop, and measuring human performance in the context of robotic systems. These topics support robotic systems in unstructured and unknown environments with a human supporting decision making, mitigating risks and extending capabilities of the human-robot team.					
☑	Full Term Credit Hours Undergraduate Min: 4 Undergraduate Max: 4	Graduate Min: Graduate Max:		Half Term Credit Hours Undergraduate Min: Undergraduate Max:	Graduate Min: Graduate Max:	
☑	Course Credit Type Undergraduate Student					
☑	Repeatability ☐ Course is Repeatable for Credit Maximum number of repeatable credits: 0			☐ Course is Y graded ☐ Can be taken more than once in the same term		

Subject: Catalog:			
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	CURRENT LISTING	**REQUESTED LISTING**
☑	Advisory Prerequisite (254 char)	Advisory Prerequisite (254 char) ROB 311
☑	Enforced Prerequisite (254 char) Minimum grade requirement:	Enforced Prerequisite (254 char) ROB 204 Minimum grade requirement: C-
☐	Credit Exclusions	Credit Exclusions

	Course Components	Graded Component	Terms Typically Offered
☑	☑ Lecture	☑	☑ Fall
	☐ Seminar	☐	☐ Winter
	☑ Recitation	☐	☐ Spring
	☐ Lab	☐	☐ Summer
	☐ Discussion	☐	☐ Spring/Summer
	☐ Independent Study	☐	

Cognizant Faculty Member Name: Leia Stirling | Cognizant Faculty Member Title: Associate Professor

SIGNATURES ARE REQUIRED FROM ALL DEPARTMENTS INVOLVED (Please Print AND Sign Name)

Contact Person: Chrisitna Hollis Email: crhollis@umich.edu Phone: 734-763-2869

CoE Curriculum Committee Representative: Print: Date:

CoE Curriculum Committee Chair: Print: Date:

Home Department Chair: Print: Jessy Grizzle Date: 10/14/2021

Cross-Listed Department Chair: Print: Date:

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Cross-Listed Department Chair: Print: Date:

DEPARTMENTAL/COLLEGE USE ONLY

Current:	**Requested:**
Course Description	Course Description Covers psychophysics, modeling a human operator within a control loop, and measuring human performance in the context of robotic systems. These topics support robotic systems in unstructured and unknown environments with a human supporting decision making, mitigating risks and extending capabilities of the human-robot team.
Class Length	Class Length Full term
Contact hours (lecture):	Contact hours (lecture): 3
Contact hours (recitation)	Contact hours (recitation) 1
Contact hours (lab)	Contact hours (lab) 0

Additional Info:

Submitted by:
Home dept

Describe how this course fits with the degree requirements:
This course will be part of the Robotics Undergraduate program pathway options. The course is intended to provide students with more depth on human-robot interaction, extending ideas introduced in ROB 204. There is a specific emphasis on mathematical models of human cognitive mechanisms in the context of interactive robotic systems.

This course is part of the emerging undergraduate major degree in Robotics. Assuming approval of the Robotics Undergraduate Program, this course will serve as an intermediate level course for students majoring in Robotics. We expect students will be ready to enroll in this course as early as the Winter 2023 semester. As a new offering in the planned Robotics Undergraduate Program, this has not been offered previously. The first offering of this course is expected to be a limited-enrollment pilot that will ramp up enrollment in future semesters. The Robotics Undergraduate Program does not plan for ABET accreditation for the immediate horizon. This course is not planned to be an essential part of an ABET accredited degree program, but has appropriate ABET objectives listed in case they are needed.

Special resources of facilities required for this course:
None

Supporting statement:
The proposed course supports design of robotic systems that have direct interactions with humans during real-time operations. The inclusion of the human operator in a closed-loop system provides capabilities for robots to be used in unstructured and unknown environments as the human can support decision making, mitigating risks and extending capabilities. This class provides context for how we can measure human perception, how the human operator can be modeled in the control loop, as well as ways to measure performance of the human in the context of robotic systems.

The course will be assessed using assignments, exams, and a final project. All assessments are individual. The breakdown is as follows:

Assignments - 65%
Final Project - 15%
Midterm Exam - 10%
Final Exam - 10%

Assignments include implementation of methods, small experiments, and paper-based modeling. For example, the assignment associated with the psychophysics module will include a small data collection and then fitting of psychometric curves to the collected data, assessing the pros and cons of the different methods and the operational interpretation of the outcomes. The human-in-the-loop control module will include computer simulation implementations of the models presented, evaluating implementations on relevant criteria. For the human motion assessment, assignments will include interpretation of data, as well as implementation of methods to take sensor measures to relevant outcome metrics.

Learning Objectives
Describe the distinction between sensation, perception, and behavior.
Design an experiment to assess the just noticeable difference for a sensory quality.
Distinguish haptic information and power exchange in force/motion signals and motor commands/haptic sensation.
Provide the pros and cons for keeping a human in the loop vs. automating a task or process.
Describe the role of biomechanics and neural control in a human-in-the-loop system.
Use quantitative and qualitative approaches to evaluate and analyze human-robot movement and interactions.
Describe the communication requirements associated with the spectrum of robots ranging from a robot as a tool to a robot as a teammate.

Schedule (15 weeks total)

Week	Topic
Week 1	History of cognitive models and the conception of self
Week 2	Psychophysics: Introduction to classical methods
Week 3	Psychophysics: Finding a Just Noticeable Difference
Week 4	Psychophysics: Signal detection theory
Week 5	Sensation and perception: Modality, mapping, and language
Week 6	Haptics: Information for cueing vs. coupling
Week 7	Feedback systems and loop closures: The role of hardware versus the human
Week 8	Human-in-the-loop Control: Motion, interaction, and impedance control
Week 9	Human-in-the-loop Control: Internal models and feedforward control
Week 10	Human-in-the-loop Control: Arbitrating decision making in the presence of modes
Week 11	Social robots: Communication for the spectrum of robots as tools to teammates
Week 12	How to measure motion: Defining metrics of performance
Week 13	How to measure motion: Kinematics
Week 14	How to measure motion: Forces and Interaction
Week 15	Final Project Presentations