UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Report No. 3717 Revised

MEMORANDUM

To: Executive Committee of Faculty Council (April 6, 2022)
Faculty Council (April 27, 2022)

From: Professor Julie Audet
Chair, Engineering Graduate Education Committee (EGEC)

Date: April 22, 2022

Re: **Creation of Collaborative Specialization in Robotics**

REPORT CLASSIFICATION

This is a major policy matter that will be considered by the Executive Committee for endorsing and forwarding to Faculty Council for vote as a regular motion (requiring a simple majority of members present and voting to carry).

PROPOSED

The University of Toronto Robotics Institute, an EDU-C in the Faculty of Applied Science & Engineering, proposes to launch Canada's first Collaborative Specialization in Robotics, designed to build a structured community of practice that combines engineering and computer science approaches to robotics and its applications, including healthcare, mobility, and advanced manufacturing.

The collaborative specialization will be open initially to MASc/MSc and PhD students from Engineering (UTIAS, BME, ECE and MIE), the Faculty of Arts & Science (Computer Science), the University of Toronto Mississauga, and the Temerty Faculty of Medicine (Rehabilitation Sciences Institute). It will be open to future expansions as other faculties become more involved in the UofT Robotics Institute.

The proposed Collaborative Specialization in Robotics will complement an existing Emphasis in Robotics, which will remain available only to MEng students in FASE.

CONSULTATION PROCESS

The proposed Collaborative Specialization in Robotics was developed in consultation with the participating graduate units. All were in support of the collaborative specialization and no major issues were identified.

RECOMMENDATION FOR COUNCIL

THAT the creation of a Collaborative Specialization in Robotics, as described in Report 3717 Revised, be approved.

University of Toronto
New Graduate
Collaborative Specialization
Major Modification Proposal

This template has been developed in line with the University of Toronto's Quality Assurance Process. It should be used to bring forward all proposals for new graduate Collaborative Specializations for governance approval under the University of Toronto's Quality Assurance Process.

Name of proposed collaborative specialization:	Collaborative Specialization in Robotics
Lead Faculty/academic division:	Faculty of Applied Science and Engineering (UofT Robotics Institute)
Lead Faculty/academic division contact:	Prof. Julie Audet, Vice Dean Graduate (FASE) Prof. Tim Barfoot (Director)
Anticipated start date of new collaborative specialization:	September 2022
Version date:	April 21, 2022

New Graduate Collaborative Specialization Proposal: Collaborative Specialization in Robotics

Lead Faculty: Applied Science and Engineering
University of Toronto

Contents

1 Specialization Rationale

The University of Toronto Robotics Institute, an EDU-C in the Faculty of Applied Science & Engineering, proposes to launch Canada's first Collaborative Specialization in Robotics, designed to build a structured community of practice that combines engineering and computer science approaches to robotics and its applications, including healthcare, mobility, and advanced manufacturing. The Collaborative Specialization in Robotics will be open initially to MASc/MSc and PhD students from the Faculty of Applied Science & Engineering (FASE), the Faculty of Arts & Science (FAS), the University of Toronto Mississauga (UTM), and the Temerty Faculty of Medicine (FoM); and is open to future expansions as other faculties become more involved in the UofT Robotics Institute.

The proposed Collaborative Specialization in Robotics will complement an existing Emphasis in Robotics, which will remain available to MEng students in FASE.

1.1 Rationale

A Collaborative Specialization in Robotics will improve the robotics graduate student experience at UofT by building a community of practice that combines engineering, computer science, and applied approaches to robotics education. It is founded on the principle that while there are many different applications of robotics (e.g., autonomous vehicles, medicine, advanced manufacturing), there are core concepts and tools (e.g., algorithms) that cut across these applications.

Robotics is a highly competitive field. At least seven major new robotics institutes have launched at universities worldwide since 2013[1]. Almost half of the 30+ universities we examined in a 2017 environmental scan were offering specialized degrees in robotics, with many of the top institutions offering robotics degrees at the graduate level (e.g., Michigan, CMU, Georgia Tech, UCSD, etc.).

Robotics is a highly interdisciplinary field. Computer science, engineering, and the applied and medical sciences each play an integral role in a robotics education; however, the existing Graduate Emphasis in Robotics is not presently available to

[1] ETH Zurich's Centre for Robotics (2019), University of Toronto Robotics Institute (2019), Waterloo Robohub (2018), Michigan Robotics Institute (2015), Georgia Tech Institute for Robotics and Intelligent Machines (2013), UCSD Contextual Robotics Institute (2015), Edinburgh Centre for Robotics (2014).

students outside of FASE who are supervised by robotics-focused faculty. This means that, unlike their engineering counterparts, the growing number of robotics-focused computer science and medical science graduate students at UofT are currently unable to graduate with a robotics designation.

A Collaborative Specialization in Robotics will attract more students to our program, bring our robotics community together, and ensure that our graduates are highly qualified for academic and industry jobs across the range of new application areas currently being transformed by robotics.

1.2 Background

In 2010, and with funding from the FASE Dean's Strategic Fund (DSF) the Institute for Robotics & Mechatronics (IRM) was formed as an EDU-C to unite robotics research and launch undergraduate and graduate robotics training options within the Faculty of Applied Science & Engineering. IRM subsequently supported and helped launch the undergraduate Engineering Science Major in Robotics, the undergraduate Minor in Robotics & Mechatronics, and the Graduate Emphasis in Robotics.

Recognizing the growing global demand for robotics talent and the increasing relevance of machine learning and AI to the field, in 2017 UTM Vice-President and Principal Ulrich Krull began developing plans to establish a major computer-science focused robotics cluster on the Mississauga campus, including at least five new faculty hires plus facilities to house new robotics labs. That same year, Profs. Barfoot (UTIAS) and Nejat (MIE) struck a Robotics Strategic Planning Committee with members from across Engineering and Computer Science, with the purpose of developing a united vision for robotics at UofT. With the support of FASE Dean Cristina Amon, the committee conducted a competitive analysis, stakeholder surveys with students and industrial collaborators, and held a full-day workshop that brought together 22 UofT faculty and other stakeholders from across FASE and FAS. In 2018, following the committee's recommendations and final report, the *UofT Robotics Strategic Plan*, robotics was added to UofT's strategic research plan, UTM began fundraising and hiring for their new robotics cluster, and plans were made to rebrand IRM as the new cross-divisional University of Toronto Robotics Institute that would unite robotics activities from engineering and computer science under a common banner. The same year, UofT was awarded an NSERC CREATE in Healthcare Robotics (HeRo) — the first robotics-focused graduate training program to cover the entire continuum of care from hospital to home. HeRo provides graduate trainees with an interdisciplinary skill set that intersects robotics, medicine, and artificial intelligence (AI), while building the soft skills needed to contribute effectively to industry.

The University of Toronto Robotics Institute and HeRo CREATE officially launched in 2019, and the newly launched robotics cluster at UTM has since expanded the number of computer science faculty in robotics at UofT (four new faculty hired at UTM as part of a robotics cluster), the number of computer science graduate courses offered in robotics, and has heavily invested in state-of-the-art facilities on the UTM campus for robotics teaching and research.

In 2021 the Robotics Institute was named as one of UofT's Institutional Strategic Initiatives (ISI) by OVPRI, supported by FAS, FASE, and UTM. One of the core objectives of the Robotics ISI is to establish the Collaborative Specialization in Robotics within the three-year mandate of the ISI program. Other ISI objectives that are complementary to the Collaborative Specialization include:

- Establishing a Collaborative Pre-Seed Research Fund to support exploratory research collaborations with core Robotics Institute members across divisions.
- Establishing an International Doctoral Cluster in Robotics. Leveraging UofT's internal International Doctoral Cluster program, we aim to establish a global robotics research alliance with key university partners in order to maximize research impact and aid student mobility.
- Launching a Robotics Leadership Training Program to boost the service leadership, science communication and outreach capacity of our students.
- Working with Advancement teams at FASE and UTM to raise funds to support training and research activities, including scholarships and student awards.

2 Participating Programs, Degrees and Names of Units

Faculty of Applied Science & Engineering

- Aerospace Science and Engineering, MASc, PhD, University of Toronto Institute for Aerospace Studies (UTIAS)
- Biomedical Engineering, MASc, PhD, Institute of Biomedical Engineering (BME)
- Electrical and Computer Engineering, MASc, PhD, The Edward S. Rogers Sr. Department of Electrical and Computer Engineering (ECE)
- Mechanical and Industrial Engineering, MASc, PhD, Department of Mechanical and Industrial Engineering (MIE)

Faculty of Arts & Science

- Computer Science, MSc, PhD, Department of Computer Science (DCS), including graduate students affiliated with UTM

Temerty Faculty of Medicine

- Rehabilitation Sciences, MSc PhD, Rehabilitation Science Institute (RSI)

3 Objectives, Added Value for Students

Academic Objectives

Currently, there is no formal program in robotics available to research-stream graduate students in Canada. We aim to achieve the following with this collaborative specialization:

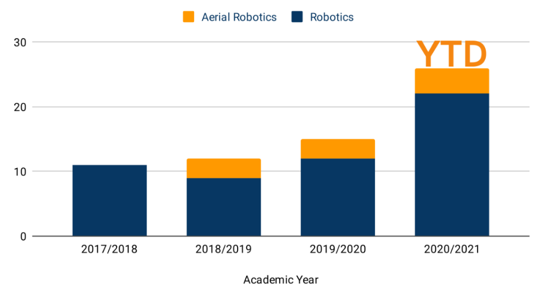
- Provide a common designation for all research-stream graduate students in robotics at the University.
- Complement a student's research thesis and coursework with an additional breadth of knowledge component in robotics through a common seminar-style course, events, and professional development skills.

Anticipated Demand

Enrollment in robotics courses and completions of robotics degree programs at both the undergraduate and graduate levels has been steadily rising.

The below infographic summarizes the demand for the Robotics Graduate Emphasis, the undergraduate Engineering Science Major and the undergraduate Minor in Robotics & Mechatronics over the last few years. All of these programs have a general growth trend.

UOFT ROBOTICS GRADUATE EDUCATION



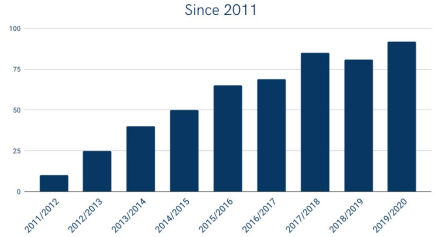
64

Robotics Emphasis Completions
Since 2017

UOFT ROBOTICS UNDERGRADUATE EDUCATION

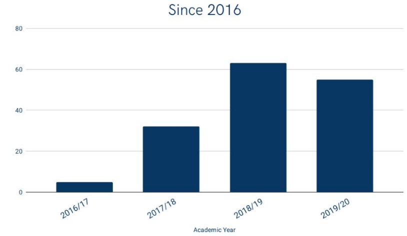
514

Robotics Minors
Since 2011



155

Robotics Eng Sci Majors
Since 2016

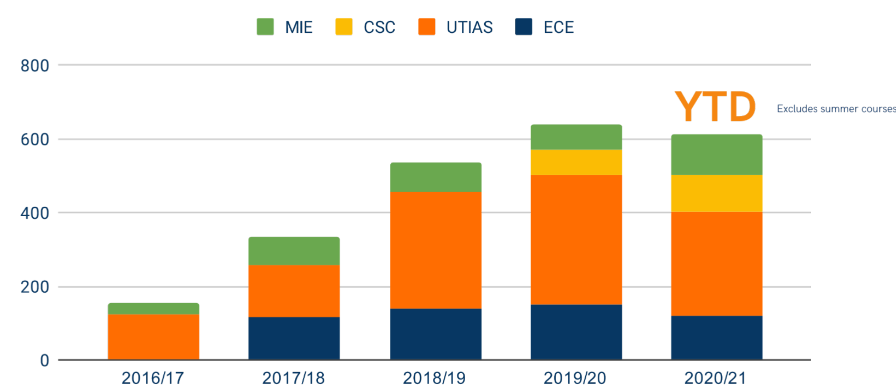


Most popular Eng Sci Major at UofT!!

UNIVERSITY OF TORONTO
Robotics Institute

The below graphic shows the total enrolment of robotics-themed students across all programs at the University.

UOFT ROBOTICS ENROLMENT



Over 90% of the UofT graduate students we surveyed in our 2017 environmental scan said it would be more appealing to come to UofT for graduate school if we offered a graduate degree in robotics. Other student recommendations included:

- Expanding the number of graduate courses offered in robotics.
- Creating more learning opportunities at the intersection of engineering and computer science (artificial intelligence).

Based on the number of graduate trainees who are supervised by our core robotics faculty (estimated as 15 faculty * eight students), at steady state we anticipate that roughly 100 students will be enrolled in the collaborative specialization at any given time, with roughly one-third graduating with the designation each year (average dwell time of MASc = two and PhD = four years).

Common Learning Experience for Students

We believe it is valuable for our robotics graduate students, whether they work on robotic surgery or unmanned aerial vehicles, to have a broad perspective on what robotics does beyond their current focus. The Collaborative Specialization in Robotics will add value by providing additional breadth of knowledge in robotics through a seminar-style course, events bringing students together, and professional skills development (e.g., our new leadership course). By providing these breadth components beyond the research thesis and courses and marking it with a designation on the transcript, we also hope to add value in terms of providing a "seal of approval" for students as they seek our jobs in the robotics sector; companies will come to recognize our Collaborative Specialization in Robotics designation with students who come with both deep technical skills as well as a broad perspective of what robotics is and could be in the future.

How this collaborative specialization is similar/different from other collaborative specialization programs at UofT

The Collaborative Specialization in Psychology and Engineering (PsychEng) includes human factors, as well as interactions between psychology and artificial intelligence. Our focus is on core robotics students. There could be a minor overlap between our proposed collaborative specialization and the PsychEng one in the area of human-robot interaction, but we see this as a positive, and those students could choose which collaborative specialization better suits their interests.

4 Admission & Specialization Requirements

- Students who have completed the collaborative specialization at the master's level will not be eligible to enrol in it again during their PhD.

- A robotics-focused research thesis.

  Topic to be deemed suitable by the Robotics Collaborative Specialization Committee through consultation with the participant's supervisor.

  Student to be supervised by a faculty member associated with the Collaborative Specialization in Robotics (these will be the core and affiliated faculty of the UofT Robotics Institute).

- ROB1830Y: Seminar-style course (0.0 FCE, CR/NCR) of UofT professors and invited academic/industry speakers (e.g., from the UofT Robotics Institute seminar series) covering all application areas of robotics.

  Excerpt from new course proposal: This is a seminar-style course where students will attend at least 8 talks from a wide variety of robotics experts. The seminar series is already being delivered by the University of Toronto Robotics Institute and provides students with opportunities to learn about areas of robotics outside their thesis research. Speakers will be both internal robotics professors as well as external visitors from other universities and industry. The proposed course formalizes attendance of this seminar series as part of a larger plan to establish a Collaborative Specialization in Robotics. All seminars will be delivered either online or in hybrid delivery mode to allow attendance by students on any campus.

  Students will be required to participate (by giving a talk) in at least one UofT Robotics Institute workshop event (there are a few offered each year on a specific topic such as Autonomous Vehicles, Manufacturing/Manipulation, Healthcare Robotics (HeRo) Summer Institute, 3MT Thesis Competition).

  This course cannot be used to fulfill the degree requirements of any individual program and must be on top of those; it will only be available to participants in the collaborative specialization.

Participants will be required to attend eight seminars as part of the collaborative specialization.

The course will be a “continuous” format course and therefore students can take multiple years to complete the eight seminars.

This course will be offered in hybrid delivery mode, meaning all students will be able to attend the seminars “live” from wherever they are and wherever the speaker is.

- Completion of one graduate half-course (0.5FCE) in robotics, chosen from any of the four groups listed below. The CS will encourage instructors of these courses to offer hybrid delivery modes wherever possible to allow students from all campuses to participate in whichever courses are the most useful to them, regardless of campus affiliation.

Group 1: Planning and Control

- AER1516H, AER1517H
  ECE557H (exclusion: ECE410H), ECE1619H, ECE1635H, ECE1636H ECE1647H, ECE1653H, ECE1657H
  MIE1064H, MIE1068H

Group 2: Perception and Learning

- AER1513H, AER1515H
  CSC2503H, CSC2506H, CSC2515H, CSC2541H, CSC2548H
  ECE516H, ECE521H, ECE1511H, ECE1512H
  JEB1433H
  ROB501H

Group 3: Modelling and Dynamics

- AER506H, AER1503H, AER1512H
  JEB1444H
  MIE1001H

Group 4: Systems Design and Integration

- AER525H (exclusion: ECE470H), AER1216H, AER1217H
  CSC2621H
  MIE505H, MIE506H, MIE1070H, MIE1075H, MIE1076H, MIE1080H MIE1809H
  ROB521H, ROB1514H, REH2000H

- (Optional) Completion of one professional development activity from the following list:
  New Robotics Leadership program (will be part of the Robotics ISI)
  Prospective Professors in Training program (we may offer a robotics-specific session)
  Entrepreneurship activity (CDL, Start, Hatchery)
  One-semester Internship with robotics company
  We considered making this mandatory but feel it may be too heavy for some students and prefer to provide it as a suggestion at the moment.

Verification of Completion of Specialization Requirements

All students enrolled in the Collaborative Specialization in Robotics must complete the specific course requirements of the collaborative specialization, in addition to or within those requirements for the degree program in their home graduate unit, where possible. The collaborative specialization director is responsible for certifying the completion of the collaborative specialization requirements, with recommendations from the Robotics Collaborative Specialization Committee. The home graduate unit is solely responsible for the approval of the student's home degree requirements.

Table 1: Comparison of Grad Emphasis (existing) and Collaborative Specialization (proposed) Requirements

	Grad Emphasis in Robotics	**Collaborative Specialization in Robotics**
Eligible Students	FASE (UTIAS, ECE, MIE, BME): MEng	FASE (UTIAS, ECE, MIE, BME): PhD, MASc FAS (DCS): PhD, MSc
Thesis Requirement	No	Yes

Seminar Course	No	Yes
Technical Courses	4 in 2 categories from list	1 from list in any category
Professional Development	Optional Activities	Optional Activities

SGS Calendar Entry

Robotics

Lead Faculty

Faculty of Applied Science and Engineering

Participating Degree Programs

- Aerospace Science and Engineering — MASc, PhD
- Biomedical Engineering — MASc, PhD
- Computer Science — MSc, PhD
- Electrical and Computer Engineering — MASc, PhD
- Mechanical and Industrial Engineering — MASc, PhD
- Rehabilitation Science — MSc, PhD

Supporting Units

- University of Toronto Robotics Institute
- University of Toronto Institute for Aerospace Studies

Overview

The graduate programs listed above participate in the Collaborative Specialization (CS) in Robotics, which aims at building a structured community of practice that combines engineering and computer science approaches to robotics.

The CS in Robotics is designed to foster cross-disciplinary training and collaboration across diverse departments at the University. Upon successful completion of the degree requirements of the participating home graduate unit and the CS, students will receive the notation “Completed Collaborative Specialization in Robotics” on their transcript.

Contact and Address

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University of Toronto Robotics Institute
Myhal Centre for Engineering Innovation & Entrepreneurship
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Toronto, Ontario M5S 1A4
Canada

Master's Level

Admission Requirements

- Applicants must meet the admission requirements of both the home graduate unit and the collaborative specialization (CS).
- Applicants must apply to and be admitted to both the CS and a participating research-stream master's degree program.
- Applicants must be supervised by a core faculty member of the collaborative specialization (list can be found on collaborative specialization website).

Specialization Requirements

- Students must meet the degree requirements of the School of Graduate Studies, the participating home graduate program, and the CS.
- The student's thesis in their home graduate program must be in the area of robotics.
- The plan of study will include at least **0.5 full-course equivalent (FCE)**:

  Courses will be offered through the CS and participating graduate units.
  Students must take one half course recognized by the CS (see the course list section) to total 0.5 FCE.
  Students must complete ROB1830Y, the Robotics Seminar Series (0.0 FCE, Credit/No Credit) in addition to their home program requirement; offered through UTIAS

Doctoral Level

Admission Requirements

- Applicants must meet the admission requirements of both the home graduate unit and the collaborative specialization (CS).
- Applicants must apply to and be admitted to both the CS and a participating doctoral degree program.
- Applicants must be supervised by a core faculty member of the CS (list can be found on collaborative specialization website).
- Students who have completed the CS at the master's level are not eligible to take it during their PhD program.

Specialization Requirements

- Students must meet the degree requirements of the School of Graduate Studies, the participating home graduate program, and the CS.
- The student's thesis in their home graduate program must be in the area of robotics.
- The plan of study will include at least **0.5 full course equivalent (FCE)**:

  Courses will be offered through the CS and participating graduate units.
  Students must complete one half course recognized by the CS (see the course list section) to total 0.5 FCE.
  Students must complete ROB1830Y, the Robotics Seminar Series (0.0 FCE, Credit/No Credit) in addition to their home program requirement; offered through UTIAS

5 Degree Level Expectations, Program Learning Outcomes & Program Structure

A collaborative specialization is intended to provide an additional multidisciplinary experience for students enrolled in, and completing the requirements of a degree program. The requirements for the Collaborative Specialization in Robotics are **in addition to** the degree requirements and are not meant to extend the student's time to degree.

Table 1: Master's DLEs

MASTER'S DEGREE-LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents [OCAV] DLEs)	**MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES**	**HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES**
EXPECTATIONS: **This Collaborative Specialization in Robotics is awarded to students who have demonstrated:**		
1. **Depth and Breadth of Knowledge** A systematic understanding of knowledge, and a critical awareness of current problems and/or new insights, much of which is at, or informed by, the forefront of the academic discipline, field of study, or area of professional practice.	Depth and breadth of knowledge is defined in Robotics as the ability to: • Describe and apply fundamental knowledge in electromechanical systems design. • Describe and apply fundamental knowledge in physics-based mathematical modeling and control. • Describe and apply fundamental knowledge in sub-fields of artificial intelligence, including but not limited to	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: • Completion of a set number of graduate courses in robotics that must fulfill a set of breadth requirements. • Completion of a core one-semester course available only to participants of the program, which includes a seminar series of UofT professors and invited

MASTER'S DEGREE-LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents [OCAV] DLEs)	MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
	reasoning and planning, machine learning, computer vision and graphics.	academic/industry speakers covering all application areas of robotics (ROB1830Y) • Thesis in the area of Robotics
2. **Research and Scholarship** A conceptual understanding and methodological competence that i) Enables a working comprehension of how established techniques of research and inquiry are used to create and interpret knowledge in the discipline; ii) Enables a critical evaluation of current research and advanced research and scholarship in the discipline or area of professional competence; and iii) Enables a treatment of complex issues and judgments based on established principles and techniques; and, on the basis of that competence, has shown at least one of the following: i) The development and support of a sustained	Research and Scholarship is defined in Robotics as the ability to: • Synthesize, describe and analyze relevant existing literature from journal or conference publications. • Identify the historical evolution and lineage of proposed methods, and attribute credit accordingly. • Describe and analyze fundamental methods (e.g., statistical hypothesis testing) for empirically evaluating the performance of proposed methods.	The program design and requirement elements that ensure these student outcomes for research and scholarship are: • Mandatory submission of a robotics-focused thesis. • The student needs to be supervised by a faculty member associated with the Robotics Collaborative Specialization. • Final course projects, which are part of most graduate-level courses in robotics.

MASTER'S DEGREE-LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents [OCAV] DLEs)	MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
argument in written form; or ii) Originality in the application of knowledge.		
3. **Level of Application of Knowledge** Competence in the research process by applying an existing body of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting.	Mainly covered through the program learning outcomes of the home program. Application of knowledge is defined in Robotics as the ability to: • Identify which abstractions and methods developed in robotics can apply to a set of constraints imposed by an application domain. • Identify the limitations, risks, and ethical issues involved in the deployment and application of robotics technologies in the application domains mentioned above.	The program design and requirement elements that ensure these student outcomes for level and application of knowledge are: • Mandatory submission of a robotics-focused thesis. • The student needs to be supervised by a faculty member associated with the Robotics Collaborative Specialization. • Mandatory participation in the regular UofT Robotics Institute seminar series of invited external speakers. • Completion of a core one-semester course available only to participants of the program, which is the Robotics Seminar Series, which covers many application areas of robotics.

MASTER'S DEGREE-LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents [OCAV] DLEs)	MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
4. **Professional Capacity/Autonomy** • The qualities and transferable skills necessary for employment requiring i) The exercise of initiative and of personal responsibility and accountability; and ii) Decision-making in complex situations; • The intellectual independence required for continuing professional development; • The ethical behavior consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research; and • The ability to appreciate the broader implications of applying knowledge to particular contexts.	Mainly covered through the program learning outcomes of the home program. Professional Capacity/Autonomy is defined in Robotics as the ability to: • Function effectively as a member or leader in multi-disciplinary teams and settings. • Demonstrate accountability and responsibility, and provide, receive, and act on constructive feedback from peers and supervisors.	The program design and requirement elements that ensure these student outcomes for professional capacity/autonomy are: • Mandatory submission of a robotics-focused thesis. • The student needs to be supervised by a faculty member associated with the Robotics Collaborative Specialization. • Final course projects, which are part of most graduate-level courses in robotics.
5. **Level of Communications Skills** The ability to communicate ideas, issues and conclusions clearly.	Mainly covered through the program learning outcomes of the home program	The program design and requirement elements that ensure these student outcomes for level of communication skills are:

MASTER'S DEGREE-LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents [OCAV] DLEs)	MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
	Communication Skills are defined in Robotics as the ability to: • Present technical problems and solutions to robotics research and general audiences, regardless of whether they have expertise in the specific problem or not. • Demonstrate concise and accurate technical writing in reports, documentation, and research papers.	• Final course projects, which are part of most graduate-level courses in robotics. • Mandatory submission of a robotics-focused thesis. • The student needs to be supervised by a faculty member associated with the Robotics Collaborative Specialization.
6. Awareness of Limits of Knowledge Cognizance of the complexity of knowledge and of the potential contributions of other interpretations, methods, and disciplines.	Mainly covered through the program learning outcomes of the home program	

Table 2: Doctoral DLEs (including direct-entry PhD)

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)	DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
EXPECTATIONS **This Collaborative Specialization in Robotics extends the skills associated with the Master's degree and is awarded to students who have demonstrated:**		
1. **Depth and Breadth of Knowledge** A thorough understanding of a substantial body of knowledge that is at the forefront of their academic discipline or area of professional practice.	Same as for MSc students in Table 1. Also covered through the program learning outcomes of the home program	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: Same as for MSc students in Table 1.
1. **Research and Scholarship** • The ability to conceptualize, design, and implement research for the generation of new knowledge, applications, or understanding at the forefront of the discipline, and to adjust the research design or methodology in the light of unforeseen problems;	Same as for MSc students in Table 1. Also covered through the program learning outcomes of the home program	The program design and requirement elements that ensure these student outcomes for research and scholarship are: Same as for MSc students in Table 1.

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)	**DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES**	**HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES**
• The ability to make informed judgments on complex issues in specialist fields, sometimes requiring new methods; and • The ability to produce original research, or other advanced scholarship, of a quality to satisfy peer review, and to merit publication.		
2. **Level of Application of Knowledge** The capacity to i) Undertake pure and/or applied research at an advanced level; and ii) Contribute to the development of academic or professional skills, techniques, tools, practices, ideas, theories, approaches, and/or materials.	Same as for MSc students in Table 1. Also covered through the program learning outcomes of the home program	The program design and requirement elements that ensure these student outcomes for level of application of knowledge are: Same as for MSc students in Table 1.
3. **Professional Capacity/Autonomy** • The qualities and transferable skills necessary for employment requiring the exercise of personal responsibility and largely autonomous initiative in complex situations;	Mainly covered through the program learning outcomes of the home program Same as for MSc students in Table 1.	The program design and requirement elements that ensure these student outcomes for professional capacity/autonomy are: Same as for MSc students in Table 1.

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)	DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
• The intellectual independence to be academically and professionally engaged and current; • The ethical behavior consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research; and • The ability to evaluate the broader implications of applying knowledge to particular contexts.		
4. **Level of Communication Skills** The ability to communicate complex and/or ambiguous ideas, issues and conclusions clearly and effectively.	Same as for MSc students in Table 1. Mainly covered through the program learning outcomes of the home program	The program design and requirement elements that ensure these student outcomes for level of communication skills are: Same as for MSc students in Table 1.
5. **Awareness of Limits of Knowledge** An appreciation of the limitations of one's own work and discipline, of the complexity of knowledge, and of the	Same as for MSc students in Table 1. Mainly covered through the program learning outcomes of the home program	The program design and requirement elements that ensure these student outcomes for awareness of limits of knowledge are:

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)	DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
potential contributions of other interpretations, methods, and disciplines. Competence in the research process by applying an existing body of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting.		Same as for MSc students in Table 1.

6 Assessment of Learning

The stated learning objectives will be assessed primarily through standard departmental mechanisms for course performance assessment (e.g., assignments, final project, presentations, exams), as well as already established mechanisms for robotics-focused thesis defenses, where the PhD committee typically includes robotics faculty associated with this collaborative specialization from both engineering and computer science.

The faculty (co-)supervisor(s) will assume the primary responsibility for monitoring and assessing how well the student is performing relative to the expected learning objectives and degree-level expectations, however, the PhD committee, the MASc committee, and the external MSc thesis reader, will also share partial responsibility to provide assessments of the student's progress throughout their degree.

The Collaborative Specialization in Robotics will include mechanisms for tracking attendance and participation of students in the core graduate seminar course in robotics, for both engineering and computer science students. It will also coordinate with SGS regarding the student's completion of all program requirements in their graduate unit.

7 Resources

The core faculty members in the Collaborative Specialization in Robotics are available to students in the home program as advisors or supervisors. If a student's program includes a thesis, it is expected that a core faculty member in the student's home department will be involved in thesis supervision. Core faculty members contribute to the collaborative specialization through teaching of the core course(s) and participating in the delivery of seminar series and other common learning elements. Some faculty may teach courses in the subject area of the collaborative specialization in the home program. Not all core faculty members are active in the collaborative specialization every year and, in many cases, simply may remain available to interested students. The list of core faculty members is available in Appendix B. Each participating degree program contributes to the collaborative specialization through student enrolments, although not necessarily every year.

Each collaborative specialization has a director and a specialization committee. Together they are responsible for admitting students to the collaborative specialization and ensuring that the faculty associated with the program have the capacity to supervise all program students. Consequently, an assessment of supervisory capacity occurs twice: once when students are admitted to their home degree program and once on their application to the collaborative specialization.

The University finds that the participation in a collaborative specialization does not normally add significantly to a faculty member's supervisory load. For the most part, students in the collaborative specialization will continue to have their thesis or major research project supervised by a faculty member in their home program who also participates in the collaborative specialization.

UTIAS will administer the core seminar course ROB1830Y which will be offered in a hybrid format with support from FASE's Edtech office.

Please see Appendix B for a list, by program, of core graduate faculty.

8 Administration

Please see Appendix C: Memorandum of Agreement.

9 Governance Process

Steps and Approvals	**Dates**
Development and consultation with unit(s)	Fall 2021
Consultation with Dean's Office (and VPAP)	Fall 2021-Winter 2022
Graduate unit approval	Winter 2022
Faculty/divisional governance	April 27, 2022
Submission to Provost's Office	April 27, 2022
Report to Committee on Academic Programs & Policy	Spring 2022
Report to Ontario Quality Council	Spring 2022

Appendix A: Collaborative Specialization Requirements & Degree Program Requirements

Please provide the following information for each participating program. The purpose is to clarify how the Collaborative Specialization requirements are accommodated within each participating program.

Following the format below, please explain if the collaborative specialization requirements are in addition to the home program requirements or if they may be counted towards regular home program requirements. State explicitly, for example, "The core course (X FCE) may be counted as one of the electives."

For collaborative specialization students in a degree program that requires a thesis or major research paper, the topic should be in the area of the collaborative specialization. For students in a coursework-only master's degree program, at least 30% of the courses for the home degree must be in the area of the collaborative specialization—this includes the core course for the collaborative specialization (please see the Quality Assurance Framework "Collaborative Specialization" definition for more details). It is not necessary to reiterate all the requirements for each degree program.

Students who have completed the collaborative specialization at the master's level are not eligible to take it during their PhD.

University of Toronto Institute for Aerospace Studies:

- **PhD in Aerospace Science and Engineering**

PhD requirements:	2.0 FCEs total coursework
	1.0 FCEs required to be AER or ROB courses
	1.0 FCEs elective space for courses

0.5 FCE (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Aerospace Science and Engineering (Transfer)**

  PhD requirements: 3.5 FCEs total coursework
  2.5 FCEs already completed during the MASc program. At least half of the required FCEs must be from AER or ROB courses.

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Aerospace Science and Engineering (Direct-Entry)**

  PhD requirements: 3.5 FCEs total coursework. At least half of the required FCEs must be courses with AER or ROB designators.

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **MASc in Aerospace Science and Engineering**

  MASc requirements: 2.5 FCEs total coursework
  0.5 FCE required course (AER1800H);
  0.5 FCE from AER or ROB courses
  1.5 FCEs elective space for coursework

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

Institute of Biomedical Engineering:

- **PhD in Biomedical Engineering**

  PhD requirements: 1.0 FCEs total coursework
  1.0 FCE of required core courses
  0.0 FCEs elective space for courses

  0.5FCE (coursework) required for the collaborative specialization would be taken in addition to the total FCE home program requirements. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Biomedical Engineering (Transfer from MASc)**

  PhD requirements: 3.0 FCE: 2.0 FCEs total coursework at the master's level plus 1.0 FCE at the PhD level
  1.0 FCE of required core courses (usually completed at the master's level)
  1.0 FCEs elective space for PhD courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Biomedical Engineering (direct-entry)**

  PhD requirements: 3.0 FCE total coursework
  1.0 FCE of required core courses
  2.0 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **MASc in Biomedical Engineering**

  MASc requirements: 2.0 FCEs total coursework
  1.0 FCE of required core courses
  1.0 FCEs elective space for coursework

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

The Edward S. Rogers Sr. Department of Electrical and Computer Engineering:

- **PhD in Electrical and Computer Engineering**

  PhD requirements: 2.5 FCEs total coursework
  2.5 FCEs elective space for courses

  0.5 FCE (coursework) required for the collaborative specialization may be counted as electives—no additional courses are required.

  - **PhD in Electrical and Computer Engineering (Transfer)**

    PhD requirements: 4.0 FCEs total coursework: 2.5 FCE at MASc level and 1.5 FCE at PhD level.
    2.5 FCEs elective space for courses

    0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

  - **PhD in Electrical and Computer Engineering (Direct-Entry)**

    PhD requirements: 4.0 FCEs total coursework
    2.5 FCEs elective space for courses

    0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **MASc in Electrical and Computer Engineering**

  MASc requirements: 2.5 FCEs total coursework
  2.5 FCEs elective space for coursework

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

Department of Mechanical and Industrial Engineering:

- **PhD in Mechanical and Industrial Engineering**

  PhD requirements: 2.5 FCEs total coursework
  2.5 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Mechanical and Industrial Engineering (Transfer)**

  PhD requirements: 3.5 FCEs total coursework
  3.5 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Mechanical and Industrial Engineering (Direct-Entry)**

  PhD requirements: 3.5 FCEs total coursework
  3.5 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **MASc in Mechanical and Industrial Engineering**

  MASc requirements: 2.0 FCEs total coursework
  2.0 FCEs elective space for coursework

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

Department of Computer Science:

- **PhD in Computer Science**

  PhD requirements: 2.0 FCEs total coursework in 4 different areas of methodologies
  2.0 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **MSc in Computer Science**

  MSc requirements: 2.0 FCEs total coursework in 3 different areas of methodologies
  2.0 FCEs elective space for coursework

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Computer Science**

  PhD requirements: 2.0 FCEs total coursework in 4 different areas of methodologies
  2.0 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Computer Science (Direct-Entry)**

  PhD requirements: 4.0 FCEs total coursework in 4 different areas of methodologies
  4.0 FCEs elective space for courses

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the home program FCE coursework requirement. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

Rehabilitation Science Institute:

- **PhD in Rehabilitation Sciences**

  PhD Requirements: 2.0 FCE total coursework
  1.5 FCE total course requirements
  0.5 core course (REH 3001)
  1.0 elective space for courses (0.5 in advanced methods or statistics and 0.5 in area related to project)

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the FCE coursework requirement if approved by the home program. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **PhD in Rehabilitation Sciences (Direct-Entry)**

  PhD Requirements: 3.5 FCE total coursework
  3.0 FCE core courses
  0.5 FCE as an advanced research methods course

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the FCE coursework requirement if approved by the home program. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

- **MSc in Rehabilitation Sciences**

  MSc Requirements: 2.5 FCE total course requirements
  1.0 FCE core courses (REH1100 and REH2001)
  1.0 FCE elective space for courses (0.5 in research methods and statistics and 0.5 in area related to research)

  0.5 FCEs (coursework) required for the collaborative specialization may be counted towards the FCE coursework requirement if approved by the home program. The seminar ROB1830Y (0.0 FCE) must be taken in addition to the home program requirements.

Appendix B: Core Faculty Research Synopses

Note for proponents: Please provide a full list **of all faculty** who intend to participate in the collaborative specialization from each participating degree program. In each instance, provide two to four recent publications that show active engagement in the field.

Core faculty members are those who are eligible to teach and/or supervise in the collaborative specialization, as appropriate. Core faculty members must hold graduate faculty membership in one of the participating degree programs. The process of identifying a graduate faculty member as a collaborative specialization core faculty member is initiated by the faculty member or the collaborative specialization director. Both the faculty member's home graduate unit chair or director and the collaborative specialization director must agree, as well as the faculty member involved. The collaborative specialization director is responsible for maintaining records of agreements concerning assignment of core faculty members to the collaborative specialization. Formal cross-appointments to the graduate faculty are not required for core faculty members.

There must be at least one faculty member listed from each participating graduate program. Collaborative specialization students must have a core collaborative specialization graduate faculty member from the student's home graduate unit as a supervisor, where a supervisor is required.

All teaching staff identified as members of the collaborative specialization are core faculty of the participating approved graduate programs and have been approved by the chair or director of their home unit for cross-appointment to the collaborative specialization. In bringing forward a proposal for a new collaborative specialization, the concern is that, in addition to being approved members of the graduate teaching staff, all proposed faculty be active in the area of the collaborative specialization. This list highlights peer review publications by the approved faculty members in the collaborative specialization area.

University of Toronto Institute for Aerospace Studies:

1. **Tim Barfoot**
   a. "State Estimation for Robotics," Barfoot T D, Cambridge University Press, 2017.
   b. "Exactly Sparse Gaussian Variational Inference with Application to Derivative-Free Batch Nonlinear State Estimation," Barfoot T D, Forbes J R, and Yoon D J, International Journal of Robotics Research (IJRR), 39(13):1473–1502, 2020.

2. **Steven Waslander**
   a. "Joint 3d proposal generation and object detection from view aggregation", J Ku, M Mozifian, J Lee, A Harakeh, SL Waslander, 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems.
   b. "A review and comparative study on probabilistic object detection in autonomous driving," D Feng, A Harakeh, SL Waslander, K Dietmayer, IEEE Transactions on Intelligent Transportation Systems.

3. **Angela Schoellig**
   a. "Safe model-based reinforcement learning with stability guarantees," F Berkenkamp, M Turchetta, A Schoellig, A Krause, Advances in Neural Information Processing Systems, 908-918.
   b. "Learning-based Nonlinear Model Predictive Control to Improve Vision-based Mobile Robot Path Tracking," CJ Ostafew, AP Schoellig, TD Barfoot, J Collier, Journal of Field Robotics 33 (1), 133-152.

4. **Jonathan Kelly**
   a. "Visual-inertial sensor fusion: Localization, mapping and sensor-to-sensor self-calibration," J Kelly, GS Sukhatme, The International Journal of Robotics Research 30 (1), 56-79.
   b. "Reducing drift in visual odometry by inferring sun direction using a bayesian convolutional neural network," V Peretroukhin, L Clement, J Kelly, 2017 IEEE International Conference on Robotics and Automation (ICRA), 2035-2042.

5. **Gabriele D'Eleuterio**
   a. "Formation Control of Balloons: A Block Circulant Approach", Sniderman, A.C., Broucke, M.E. and D'Eleuterio, G.M.T., American Control Conference, Chicago, IL, 1463-1468, 2015.

b. "Synthesis of Recurrent Neural Networks for Dynamical System Simulation", Trischler, A.P. and D'Eleuterio, G.M.T., Neural Networks, 2015.

Institute of Biomedical Engineering:

1. Alex Mihailidis

a. “Hand extension robot orthosis (HeRo) glove: development and testing with stroke survivors with severe hand impairment,” A Yurkevixch, D Hebert, RH Wang, A Mihailidis, 2019, IEEE Transactions on Neural Syastems and Rehabilitation Engineering, 27, 5, 916-926.
b. “Intelligent wheelchair control strategies for older adults with cognitive impairment: user attitudes, needs and preferences,” P Viswananthan, EP Zambalde, G Foley, JL Graham, RH Wang, B Adhikari, AK Mackworth, A Mihailidis, WC Miller, IM Mitchell, Autonomous Robotics, 41, 3, 539-554.

2. Milos Popovic

a. “A Mass-Producible Washable Smart Garment with Embedded Textile EMG Electrodes for Contorl of Myoelectric Prostheses: A Pilot Study,” M Alizadeh-Meghrazi, G Sidhu, S Jain, M Stone, L Eskandarian, A Toossi, MR Popovic, Sensors, 22, 2, 666.
b. “Closed loop control of standing neuroprosthesis using PID controller,” H Rouhani, M Same, K Masani, YQ Li, MR Popovic, 2017 Conference on Systems, Man and Cybernetics, 2237-2242.

3. Jose Zariffa

a. “Analysis of the hands in egocentric vision: A survey,” A Bandini, J Zariffa, IEEE Transactions on pattern analysis and machine intelligence, 2020.
b. “Selective peripheral nerve recordings from nerve cuff electrodes using convolutional neural networks,” RG Koh, M Balas, AI Nachman, J Zariffa, Journal of Neural Engineering, 2020, 17(1), 016042.

Department of Mechanical and Industrial Engineering:

1. Yu Sun

a. “Nanonewton force-controlled manipulation of biological cells using a monolithic MEMS microgripper with two-axis force feedback,” K Kim, X Liu, Y Zhang, Y Sun, Journal of micromechanics and microengineering 18, 055013.
b. “Autonomous robotic pick-and-place of microobjects,” Y Zhang, BK Chen, X Liu, Y Sun, IEEE transactions on robotics 26 (1), 200-207.

2. **Xinyu Liu**
   a. "A fully automated robotic system for microinjection of zebrafish embryos," W Wang, X Liu, D Gelinas, B Ciruna, Y Sun, PloS one 2 (9), e862.
   b. "A Soft Robotic Gripper with Anti-Freezing Ionic Hydrogel-Based Sensors for Learning-Based Object Recognition," R Zuo, Z Zhou, B Ying, X Liu, 2021 IEEE International Conference on Robotics and Automation (ICRA)3.

3. **Goldie Nejat**
   a. "Robotic urban search and rescue: A survey from the control perspective," Y Liu, G Nejat, Journal of Intelligent & Robotic Systems 72 (2), 147-165.
   b. "Acceptance and attitudes toward a human-like socially assistive robot by older adults," WYG Louie, D McColl, G Nejat, Assistive Technology 26 (3), 140-150.

4. **Eric Diller**
   a. "Biomedical applications of untethered mobile milli/microrobots," M Sitti, H Ceylan, W Hu, J Giltinan, M Turan, S Yim, E Diller, Proceedings of the IEEE 103 (2), 205-22.
   b. "Millimeter-scale flexible robots with programmable three-dimensional magnetization and motions," T Xu, J Zhang, M Salehizadeh, O Onaizah, E Diller, Science Robotics 4 (29).

The Edward S. Rogers Sr. Department of Electrical and Computer Engineering:

1. **Mireille Broucke**
   a. "Local control strategies for groups of mobile autonomous agents," Z Lin, M Broucke, B Francis, IEEE Transactions on automatic control 49 (4), 622-629.
   b. "Stabilisation of infinitesimally rigid formations of multi-robot networks," L Krick, ME Broucke, BA Francis, International Journal of control 82 (3), 423-439.

2. **Manfredi Maggiore**
   a. "Maneuvering control of planar snake robots using virtual holonomic constraints," A Mohammadi, E Rezapour, M Maggiore, KY Pettersen, IEEE Transactions on Control Systems Technology 24 (3), 884-899.

b. “Necessary and sufficient graphical conditions for formation control of unicycles,” Z Lin, B Francis, M Maggiore, IEEE Transactions on automatic control 50 (1), 121-127.

UTM/Department of Computer Science:

1. Jessica Burgner-Kahrs

a. “Continuum robots for medical applications: A survey,” J Burgner-Kahrs, DC Rucker, H Choset, IEEE Transactions on Robotics 31 (6), 1261-1280.

b. “A Telerobotic System for Transnasal Surgery,” J Burgner, DC Rucker, HB Gilbert, PJ Swaney, PT Russell, KD Weaver, IEEE Transactions on Mechatronics, 1-11.

2. Florian Shkurti

a. “Multi-domain monitoring of marine environments using a heterogeneous robot team,” F Shkurti, A Xu, M Meghjani, JCG Higuera, Y Girdhar, P Giguere, BB Dey, …, 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems.

b. “Underwater multi-robot convoying using visual tracking by detection,” F Shkurti, WD Chang, P Henderson, MJ Islam, JCG Higuera, J Li, ..., 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems.

3. Animesh Garg

a. “Making sense of vision and touch: Self-supervised learning of multimodal representations for contact-rich tasks,” MA Lee, Y Zhu, K Srinivasan, P Shah, S Savarese, L Fei-Fei, A Garg, ..., 2019 International Conference on Robotics and Automation (ICRA), 8943-8950.

b. “Learning by Observation for Surgical Subtasks: Multilateral Cutting of 3D Viscoelastic and 2D Orthotropic Tissue Phantoms”, A Murali*, S Sen*, B Kehoe, A Garg, S McFarland, S Patil, WD Boyd, ..., IEEE International Conference on Robotics and Automation (ICRA), 1202 - 1209.

4. Igor Gilitschenski

a. “maplab: An Open Framework for Research in Visual-inertial Mapping and Localization,” T Schneider, M Dymczyk, M Fehr, K Egger, S Lynen, I Gilitschenski, ..., IEEE Robotics and Automation Letters 3 (3), 1418 - 1425.

b. “The Voliro Omniorientational Hexacopter: An Agile and Maneuverable Tiltable-rotor Aerial Vehicle,” M Kamel, S Verling, O Elkhatib, C Sprecher, P Wulkop, ZJ Taylor, ..., IEEE Robotics & Automation Magazine.

5. Raquel Urtasun

a. "Are we ready for autonomous driving? the kitti vision benchmark suite," A Geiger, P Lenz, R Urtasun, 2012 IEEE conference on computer vision and pattern recognition, 3354-3361.
b. "Monocular 3d object detection for autonomous driving", X Chen, K Kundu, Z Zhang, H Ma, S Fidler, R Urtasun, Proceedings of the IEEE Conference on Computer Vision and Pattern.

Rehabilitation Sciences Institute:

1. Alex Mihailidis

a. "Hand extension robot orthosis (HeRo) glove: development and testing with stroke survivors with severe hand impairment," A Yurkevixch, D Hebert, RH Wang, A Mihailidis, 2019, IEEE Transactions on Neural Syastems and Rehabilitation Engineering, 27, 5, 916-926.
b. "Intelligent wheelchair control strategies for older adults with cognitive impairment: user attitudes, needs and preferences," P Viswananthan, EP Zambalde, G Foley, JL Graham, RH Wang, B Adhikari, AK Mackworth, A Mihailidis, WC Miller, IM Mitchell, Autonomous Robotics, 41, 3, 539-554.

2. Milos Popovic

a. "A Mass-Producible Washable Smart Garment with Embedded Textile EMG Electrodes for Contorl of Myoelectric Prostheses: A Pilot Study," M Alizadeh-Meghrazi, G Sidhu, S Jain, M Stone, L Eskandarian, A Toossi, MR Popovic, Sensors, 22, 2, 666.
b. "Closed loop control of standing neuroprosthesis using PID controller," H Rouhani, M Same, K Masani, YQ Li, MR Popovic, 2017 Conference on Systems, Man and Cybernetics, 2237-2242.

3. Rosalie Wang

a. "Robots to assist daily activities: views of older adults with Alzheimer's disease and their caregivers", RH Wang, A Sudhama, M Begum, R Huq, A Mihailidis, International Psychogeriatrics. Cambridge University Press; 2017; 29(1):67-97.
b. "Blind spot sensor systems for power wheelchairs: obstacle detection accuracy, cognitive task load, and perceived usefulness among older adults," A Pellichero, KL Best, F Routhier, P Viswanathan, RH Wang, WC Miller, 2021, Disability Rehabilitation: Assistive Technology. Sdfasdf10.010.1080/10.1080/17483107.2021.1983654

4. Jose Zariffa

a. "Analysis of the hands in egocentric vision: A survey," A Bandini, J Zariffa, IEEE Transactions on pattern analysis and machine intelligence, 2020.
b. "Selective peripheral nerve recordings from nerve cuff electrodes using convolutional neural networks," RG Koh, M Balas, AI Nachman, J Zariffa, Journal of Neural Engineering, 2020, 17(1), 016042.