2020 – 2021
PhD in Robotics
GRADUATE HANDBOOK

GEORGIA INSTITUTE of TECHNOLOGY

January 2021

Robotics PhD Handbook

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Purpose of this Handbook

The purpose of this handbook is to familiarize Robotics graduate students with degree program requirements, policies, procedures, and the resources available to students and is intended to be a supplement to the General Catalogs, Student Handbooks of Georgia Tech, and academic departments. The info here does not replace nor supersede the materials in those resources.

As Robotics is an interdisciplinary program, students are responsible for understanding the policies and procedures for both their major programs and their home department in addition to the General Catalogs. The home department has ultimate decision-making responsibility for students assigned to their "home school."

Although students are encouraged to seek advice from the Robotics Program Director, faculty advisors, home departments, and the Academic Advisor, the Georgia Tech Registrar's Office and the Graduate Studies and other resources on campus, it is ultimately the student's responsibility to know and meet the rules and regulations for degree completion
See the Appendix sections for additional various resources, including faculty and staff contact information and important websites.

PhD Program in Robotics

Offered jointly by the College of Computing and the College of Engineering, the Ph.D. program in Robotics is the first truly multidisciplinary robotics degree of its kind in the world—and only the second robotics doctorate offered in the U.S. The program involves the schools of Interactive Computing, Electrical & Computer Engineering, Mechanical Engineering, Biomedical Engineering and Aerospace Engineering.

We educate a new generation of robotics researchers who are prepared to be impactful contributors upon entering the high-tech workforce. The Institute for Robotics & Intelligent Machines (IRIM) serves as the flagship for Tech's robotics efforts; therefore, IRIM has an integral relationship with the program, and many IRIM faculty members serve as research advisors to students pursuing the degree. The Robotics program supports Tech's mission to provide instruction in disciplines related to science, technology, and interdisciplinary areas.

Admissions

Final admission decisions will be made by the Robotics Ph.D. Program Committee in coordination with the home units. They are based on a combination of factors, including academic degrees and records, the statement of purpose, letters of recommendation, test scores, and relevant work experience. Also considered is the appropriateness of the applicant's

goals to the Robotics Ph.D. Program, their expected abilities in carrying out original research, and the faculty research interests. Particular efforts are made to recruit women and members of underrepresented minority groups.

For questions regarding admissions, please contact school representatives of the Robotics faculty coordinators (see Personnel Info on this handbook).

Announcements and other important information is sent via the mailing list: phd-robo-official, so be sure to read these emails and mark them as safe in your inbox. All new students are added to this list before phase 2 registration.

Transfer Admissions

Students can transfer into the Robotics PhD if they are currently enrolled in another graduate program at Georgia Tech.

Submit following items to the Robotics Program Director:

- Student cover letter/personal statement stating the reasons for transferring to Robotics.
- Current GT and undergraduate transcripts.
- A recommendation email letter from each the advisor/co-adviser.

Each transfer case is reviewed and voted on by the ROBO PhD committee. If approved, a Change of Major Form will be completed by the student's current program and the Robotics Program Director.

New Student Orientation

There will be a new student orientation for all new Robotics PhD students the week before classes start in Mid-August. It will consist of a short presentation by the director on the degree requirements, and several events organized by the RoboGrads student organization. This will be in addition to the orientation the incoming students may have with their home schools.

Academic Advising

For advice on which courses to take and when to take them, students should turn to the home school representative to the Robotics faculty coordinators (see personnel info on this handbook) and/or their thesis advisor.

Advising on non-academic issues can be sought through the Robotics PhD Academic Advisor including:

- General advising and CoC registration Info
- Permits for quals registration
- Quals, proposal, and thesis defense Forms
- Transfer credit requests
- Change of majors (including add a MSCS degree)
- Minor form approvals (with faculty advisor signature)

Note the Robotics PhD Academic Advisor may sign documents requiring a signature from the Robotics Graduate Coordinator, such as thesis and minor forms.

Contact information for the PhD Academic Advisor can found in the Personnel Info section of this handbook.

Course requirements

Program of Study

The Ph.D. curriculum makes extensive use of existing courses in the College of Computing and the College of Engineering. Three additional courses provide a one-semester introduction to robotics topics and a two-semester multidisciplinary robotics research experience. Students are required to complete 36 semester hours of coursework in core robotics areas: Mechanics, Controls, Perception, Human-Robot Interaction (HRI), and Artificial Intelligence (AI) & Autonomy.

The main emphasis of the Ph.D. program is the successful completion of an original and independent research thesis. The degree requirements are designed around this goal.

Minimum Requirements

- Completion of 36 semester hours of courses with a letter grade
- Passing a comprehensive qualifying exam with written and oral components.
- Successfully conducting, documenting, and defending a piece of original research culminating in a doctoral thesis.

1. *Ph.D. Robotics Degree Requirements – 36 semester hours with a letter grade*

Component	Courses	Hours Required
Intro to Robotics Research	A new course CS/AE/ECE/ME 7785, Introduction to Robotics Research.	**3**

Foundation Courses	Three foundation courses, each selected from distinct core areas: Mechanics, Controls, Perception, Artificial Intelligence, and Human-Robot Interaction (HRI).	**9**
Elective Courses	Three targeted elective courses, each selected from the same three core areas used for the foundation courses.	**9**
Multidisciplinary Robotics Research	Two new courses CS/AE/ECE/ME 8750 and CS/AE/ECE/ME 8751, Multidisciplinary Robotics Research I and II.	**6**
Courses Outside the Major (Doctoral Minor Field of Study)	Three courses outside the major area to provide a coherent minor in accordance with Institute policies.	**9**
	TOTAL	**36**

See Appendix for course listings details.

Program of Study Coursework Plan

Students must submit a coursework plan via a Program of Study (POS) to the Program Director, throughout their program including:

- End of the first semester
- Before Quals
- Before Thesis Proposal
- Anytime there is a significant change to coursework

Ph.D. Candidacy

Admission to PhD Candidacy requires that the student:

- Complete the requirements for training in Responsible Conduct for Research (RCR);
- Complete all course requirements (except the minor);
- Achieve a satisfactory scholastic record;
- Pass the comprehensive examination;
- Submit a formal statement naming the dissertation reading committee and delineating the research topic for approval to the school chair and Graduate Students (on behalf of the Vice Provost for Graduate Education and Faculty Affairs).

Responsible Conduct for Research (RCR)

All doctoral students at Georgia Tech are required to complete a two-step RCR training process.

- The first step is an online training course that must be completed within 90 days of a student starting the Ph.D. program.
- The second step is an in-person training course. There is a general PHIL 6000 as well as courses offered by specific academic units, such as BME 7004. Check with your home school to see if the PHIL 6000 or a specific RCR course is required. This 2-credit hour course is taken on a pass/fail basis, and all students must pass the course to receive the RCR credit. Students are not able to be admitted to candidacy without completing the RCR courses.

Minor Field of Study

The Robotics Ph.D. Minor consists of three related courses (nine semester credit hours) outside of robotics that forms a coherent field of study in accordance with the Institute's policies. The minor courses must be distinct from any of the robotics core areas (i.e., are not listed under any of the 5 core areas on this website) but can be taken from the student's home school as long as they are distinct from robotics courses (e.g., ECE-ROBO student can take ECE circuits courses or ME students can take fluid mechanics courses).

• To officially declare your minor with the Institute, there is a required form, The Doctoral Minor form, which is available through the GT Office of Graduate Studies via docusign: https://grad.gatech.edu/theses-dissertations-forms

This form must be signed by your faculty advisor and the Robotics Graduate Coordinator. Generally, this form is submitted at the time of the thesis proposal, but must be completed before graduation.

• Students must also submit an internal form, the ROBOTICS PH.D. PROGRAM MINOR JUSTIFICATION, to the Robotics Program Director with updated Program of Study form:

http://phdrobotics.gatech.edu/sites/default/files/pdf/PhD_ROB_Minor_Justification.pdf

Qualifying Exam

The purpose of the comprehensive exam is to:

· Assess the student's general knowledge of the degree area

· Assess the student's specialized knowledge of the chosen research area

The comprehensive examination provides an early assessment of the student's potential to satisfactorily complete the requirements for the doctoral degree. As such, it requires that

fundamental principles be mastered and integrated so that they can be applied to solving problems relevant to robotics.

Procedure

The Robotics Ph.D. qualifying has to components and the student is required to pass both to continue in the program:

– Course-based GPA requirement

– Comprehensive Oral Examination

To pass the course-based part, the student must maintain a GPA of 3.5 or higher in 4 courses taken at Georgia Tech from exactly 2 distinct core areas form the 5 core areas of robotics curriculum. Two of these courses must be foundation courses (1 course from each core area, say core area, C1 and core area, C2). The remaining two courses may be either elective or foundation with one course from the first core area, C1, and the second course from the second core area, C2. Two Foundation courses from the same core area are accepted only if credit is allowed for both courses simultaneously (i.e., only if they cover different subject areas). The student must complete the four courses for the GPA requirement by the end of the 6th semester (which includes summer semesters) of starting in the program.

The 2nd component of the ROBO qualifying exam is a comprehensive oral examination administered by an exam committee of at least three (3) Robotics faculty members. The committee must include the student's primary advisor. Goals of the oral exam include the following:

• Determine student's ability to understand and apply fundamental concepts in the general area of Robotics

• Determine the student's ability to conduct independent research and review, synthesize, and evaluate previous work from the literature

• Identify areas of weakness that the student may need to improve upon.

The student will prepare for the examination based on a specific research topic assigned by the exam committee in consultation with the student three weeks in advance. The first attempt for the comprehensive oral exam must be made before the end of the student's 5th semester (which includes summer semesters) in the program. If the student fails the oral exam the first time, he/she is allowed only 1 re-take and passing of the exam in order to remain in the Ph.D. program. The re-take of the oral exam must be on the same general topic and be administered by the same Committee as the original exam barring any unforeseen or extraneous circumstances. The exam must be completed by the end of the 8th semester (which includes summer semesters) of starting in the Ph.D. program.

Quals Appeals Process

If a student fails the oral exam on his/her second attempt, he/she has the right to appeal the decision to the Program director who will refer the matter to the Program faculty to confirm or override the outcome of the qualification examination process. The Program faculty may hear

from only the voting-eligible student's advisor and the Chair of the exam committee before reaching a decision of whether the student can remain in the program by secret ballot.

Ph.D. Thesis

The Ph.D. dissertation describes the results of a research project and demonstrates that the candidate possesses powers of original thought, talent for research, and ability to organize and present findings.

Dissertation Advisory Committee

The student presents and defends a written Ph.D. proposal to a Dissertation Advisory Committee of at least five faculty members approved by the Robotics Program Committee. The Dissertation Advisory Committee consists of five or more members where:

- At least three members must be faculty affiliated with the Robotics Program or from the student's Home School (CoC, AE, BME, ECE, ME).
- At least two members must be from outside of the student's Home School

Ph.D. Dissertation Proposal

The objective of the Ph.D. Proposal is to allow an early assessment of your chosen topic of research for the satisfactory completion of the doctoral degree. The proposal should delineate your specific area of research by stating the purpose, scope, methodology, overall organization, and limitations of the proposed study area. The proposal must include a review of the relevant literature and indicate the expected contribution of the research.

The proposal should be organized as follows:

- Summary - limited to 200 words.
- Table of Contents
- Project Description - a clear statement of the work to be undertaken. Limited to 15 pages single-spaced (30 pages double spaced) and including all graphic elements and tables.
- Bibliography

Pages should be of standard size (8½" x 11"; 21.6 cm x 27.9 cm) with minimum 1" or 2.5 cm margins at the top, bottom, and on each side. The minimum type font size is 10 to 12 points.

Submit the following documents to the Chair, Robotics Ph.D.Program:

- One copy of the dissertation proposal as detailed above;
- If applicable, an up-to-date Program of Study showing all classes taken so far;
- Ph.D.Proposal Review Request form – signed by both student and advisor

More information and form on the thesis proposal guidelines available at:
http://phdrobotics.gatech.edu/sites/default/files/pdf/Phdproposal_guidelines_v5.pdf

Dissertation Defense

The dissertation, when completed, must be publicly defended before an Examination Committee approved by the Graduate Studies office. In most instances, the Examination Committee is expected to be the same as the Dissertation Advisory Committee. If a candidate should fail to

pass the final oral examination, the Examining Committee may recommend permission for one additional examination. It is expected that the dissertation results will be published in peer-reviewed journals and conferences.

Details on preparing and submitting a dissertation according to institute guidelines are available on the http://www.gradadmiss.gatech.edu/theses-dissertations.

Students should also follow the policies and procedures for the thesis of their home school.

Additional requirements for Thesis Proposal and Defense

Students are responsible for announcing their thesis proposal and defense presentations 10-14 days before the event. Please send emails to the following listservs and "**CC" your thesis committee members:**

- Home unit listserv
- phd-robo-official@lists.gatech.edu
- announcements@grad.gatech.edu
- phdprogram@robotics.gatech.edu

After both the thesis proposal and defense presentations, students are responsible for initiating the DocuSign process for the *"Request for Admission to Ph.D. Candidacy"* and "*Thesis Approval*" forms, which can be found here, under the `Doctoral Students' header. In the form, the Grad Coordinator should be the name and email of the Robo Academic Advisor, while students should list the School Chair of their home school and all committee members. Note under "School," please list as "ECE - Robotics, AE - Robotics etc" so both major and home school are recorded.

Last semester Registration Options

Students that are completing their Ph.D. may find that the timing of their defense, graduation, and start of their subsequent employment leads to an ambiguity in how they should register for their final semester at Georgia Tech. There are, in general, three options (see Pages 5-6 of the Thesis Manual for more details and rules).

- Register as normal (i.e., 9000 & 8997/8). This works fine if the final version of your thesis is submitted in time for graduation in your last semester (see the deadlines), and there are no funding limitations.
- The 1-credit hour option. Students in their graduating semester can register for only 1 hour of 9000. Such students are, of course, not full-time and will therefore not receive a tuition waiver or be able to be paid as a GTA or GRA. These students must therefore pay the 1-hr of tuition and fees (~$1800/in-state and ~$2400/out-of-state). Students may be hired as a Graduate Assistant (GA) by their advisor and paid hourly, depending on advisors and their department. **[**NOTE: Students who are US citizens are ineligible for **student health insurance** if they are registered for less than 4 credit hours. Such students should contact STAMPS Health Services and consider their options before registering for 1-credit hour.] Students can use the 1-credit hour option only once while at Georgia Tech.
- Enrollment Waiver. This is for students who missed the final submission deadline for their target graduating semester, but have successfully defended, submitted their thesis, and are

ready to start their job. They therefore have to stay 'on the books' at Georgia Tech to graduate the following semester, even though they may not ever be on campus during the semester. The Enrollment Waiver allows a student to stay 'on the books' and not register for any hours or pay any money. To use the Enrollment Waiver, complete the form via Grad Studies docusign. Note that all thesis-related forms must be completed and submitted for the Enrollment Waiver to be approved.

If none of these seem to fit, students should discuss their case with the Registrar's Office.

Online Application for Graduation OAG

Refer to the Institute's Online Application for Graduation (OAG) and submit a petition to graduate to the registrar **before** Phase I registration of the semester preceding the semester in **which** a student expects the degree. This allows time to correct any unfulfilled requirements identified by the Office of Graduate Studies. See the GT academic calendar for OAG deadlines: https://registrar.gatech.edu/calendar

Transfer credit and Course Waivers

There is no formal transfer of credit for the Ph.D. degree where classes taken at another institute would appear on the Georgia Tech transcript. However, graduate coursework completed at other schools can be used toward the Ph.D. coursework requirement.

To request approval course waivers, students should send an email to the Robo Academic Advisor with the transcripts and syllabus from the other school. Please include the name of the course(s) from the other school and which course at GT it most equivalent to (for instance, "I believe CICS 5746 is equivalent to CS 7630") and if it is a core or elective requirement. Website links to other schools and/or GT courses/syllabi are helpful.

Note CS/AE/ECE/ME/BME/PHYS 7785, CS/AE/ECE/ME 8750, and CS/AE/ECE/ME 8751 cannot be waived.

Requests for course waivers may not be submitted during Phase II registration and will be reviewed after the first two weeks of classes.

MS on the way

Ph.D. students can obtain an MS degree "on the way." Generally, the MS degree is completed through a student's home unit, so please check with your home unit for specific requirements.

Complete the Graduate Level Change form. Fill out the top part of the form, select 'Add A Master's Degree Level' and bring the form to the Robo Academic Advisor and then to the academic department of the MS degree. Submit this form to the registrar **before** Phase I registration of the semester preceding the semester in which a student expects the degree. This allows time to correct any unfulfilled requirements identified by the Graduate Office or Registrar.

During the semester preceding the semester when the MS degree is expected, a student must submit an Online Application for Graduation.

To add MSCS, please see the Robo Academic Advisor, Stephanie Niebuhr.

If you are from outside of the CoC, current CS courses will need to be reviewed by the CoC Associate Dean.

Appendix

Administration and Governance

Program Director
Dr. Nader Sadegh

Director of Graduate Program Services
Rebecca Wilson

Academic Advisor (for Machine Learning and Robotics PhD students)
Stephanie Niebuhr

Faculty Coordinators

For questions about academic and research components of the program, contact the faculty member for your area. All questions about application procedures and processes, as well as additional contact information, may be found on the schools' websites.
Mechanics: Frank Hammond, ME/BME
Control: Patricio Vela, ECE
Perception: Jim Rehg, IC
HRI: Karen Feigh, AE

Additional Information, forms, and Links

Associated Faculty Members: http://robotics.gatech.edu/all

RoboGrads student organization**:** http://robograds.gatech.edu/

Institute for Robotics and Intelligent Machines (IRIM): https://robotics.gatech.edu/

Program of study form:
http://phdrobotics.gatech.edu/sites/default/files/pdf/PhD_ROB_ProgStudy_2012.pdf

General Catalog: http://www.catalog.gatech.edu/rules/

Catalog Information for Grad Students: http://www.catalog.gatech.edu/academics/graduate/

Registrar's Office: http://www.registrar.gatech.edu • Registration, Graduation, Commencement, Degree Completion Verification • Enrollment Certification • Letters of Completion • Institute Academic Policy

Office of International Education: www.oie.gatech.edu • Visa and Immigration Matters • Optional Practical and/or Curricular Practical Training Matters

Bursar's Office: http://www.bursar.gatech.edu • Student financial accounts, Fee Payments • Refunds

Center for Career Discovery: http://www.careerdiscovery.gatech.edu/ • Internship Opportunities

GT Graduate Studies Office: http://www.grad.gatech.edu • Thesis Deadlines, Thesis Submission Procedures and Forms

Student Financial Assistance: http://www.finaid.gatech.edu • Loans • Tuition Waivers • Fellowships

Course listings

Core Area Courses

The following courses are in the robotics core areas of Mechanics, Control, Perception, Artificial Intelligence, and Human-Robot Interaction (HRI). They are used to select three foundation courses and three targeted elective courses.

Foundation courses are marked by an asterisk (*).

Component	Courses
Mechanics	• AE 6210*, Advanced Dynamics I – Kinematics of particles and rigid bodies, angular velocity, inertia properties, holonomic and nonholonomic constraints, generalized forces. Prerequisite: AE 2220. 3 credit hours • AE 6211, Advanced Dynamics II – A continuation of AE 6210. Equations of motion, Newtonian frames, consistent linearization, energy and momentum integrals, collisions, mathematical representation of finite rotation. Prerequisite: AE 6210. 3 credit hours • AE 6230, Structural Dynamics – Dynamic response of single-degree-of-freedom systems, Lagrange's equations; modal decoupling; vibration of Euler-Bernoulli and Timoshenko beams, membranes and plates. Prerequisites: AE 3120, AE 3515. 3 credit hours • AE 6263, Flexible Multi-Body Dynamics – Nonlinear, flexible multi-body dynamic systems, parameterization of finite rotations, strategies for enforcement of holonomic and non holonomic constraints, formulation of geometrically nonlinear structural elements, time-integration techniques. Prerequisites: AE 6211, AE 6230. 3 credit hours • AE 6270, Nonlinear Dynamics – Nonlinear vibration methods through averaging and multiple scales, bifurcation, periodic and quasi-periodic systems, transition to chaos, characterization of chaotic vibrations, thermodynamics of chaos, chaos control. Prerequisite: AE 6230. 3 credit hours • AE 6520, Advanced Flight Dynamics — Reference frames and transformations, general equations of unsteady motion, application to fixed-wing, rotary-wing and space vehicles, stability characteristics, flight in turbulent atmosphere. 3 credit hours • BMED 8813*, Robotics — Robot kinematics, statics, and dynamics. Open-chain manipulators and parallel manipulators as well as an understanding of trajectory planning and non-holonomic systems. 3 credit hours

	• CS 7496, Computer Animation — Motion techniques for computer animation and interactive games (keyframing, procedural methods, motion capture, and simulation) and principles for storytelling, composition, lighting, and interactivity. 3 credit hours • ME 6405, Introduction to Mechatronics – Modeling and control of actuators and electro-mechanical systems. Performance and application of microprocessors and analog electronics to modern mechatronic systems. Prerequisites ME 3015 or equivalent, or with the consent of the instructor. 3 credit hours • ME 6407*, Robotics – Analysis and design of robotic systems including arms and vehicles. Kinematics and dynamics. Algorithms for describing, planning, commanding and controlling motion force. Prerequisites ME 3015 or ECE 3085. 3 credit hours • ME 6441*, Dynamics of Mechanical Systems – Motion analysis and dynamics modeling of systems of particles and rigid bodies in three-dimensional motion. Prerequisites: ME 3015 or equivalent, or with the consent of the instructor. 3 credit hours • ME 6442, Vibration of Mechanical Systems – Introduction to modeling and oscillatory response analysis for discrete and continuous mechanical and structural systems. Prerequisites: ME 3015 and ME 3201. 3 credit hours • ME 7442, Vibration of Continuous Systems – Equations of motion and oscillatory response of dynamic systems modeled as continuous media. Prerequisites: ME 6442 or equivalent, or with the consent of the instructor. 3 credit hours
Control	• AE 6252, Smart Structure Control – Modeling smart sensors and actuators, development of closed loop models, design of controllers, validation of controllers, application to vibration control, noise control, and shape control. Prerequisite: AE 6230. 3 credit hours • AE 6504, Modern Methods of Flight Control – Linear quadratic regulator design. Model following control. Stochastic control. Fixed structure controller design. Applications to aircraft flight control. Prerequisite: AE 3521. 3 credit hours • AE 6505, Kalman Filtering – Probability and random variables and processes; correlation; shaping filters; simulation of sensor errors; Wiener filter; random vectors; covariance propagation; recursive least-squares; Kalman filter; extensions. Prerequisite: AE 3515. 3 credit hours • AE 6506, Guidance and Navigation – Earth's shape and gravity. Introduction to inertial navigation. GPS aiding. Error analysis. Guidance systems. Analysis of the guidance loop. Estimation of guidance variables. Adjoint analysis. Prerequisite: AE 3521. 3 credit hours • AE 6511, Optimal Guidance and Control – Euler-Lagrange formulation; Hamilton-Jacobi approach; Pontryagin's minimum principle; Systems with quadratic performance index; Second variation and neighboring extremals; Singular solutions; numerical solution techniques. Prerequisite: AE 3515. 3 credit hours • AE 6530*, Techniques for analysis and description of multivariable linear systems. Tools for advanced feedback control design for these systems, including computational packages. Credit will not be awarded for both AE 6530 and ECE 6550 or AE 6530 and ME 6401. 3 credit hours. • AE 6531, Robust Control I – Robustness issues in controller analysis and design. LQ analysis, H2 norm, LQR, LQG, uncertainty modeling, small gain theorem, H-infinity performance, and the mixed-norm H2/H-infinity problem. Prerequisite: ECE 6550. 3 credit hours • AE 6532, Robust Control II – Advanced treatment of robustness issues. Controller analysis and design for linear and nonlinear systems with structured and non-structured uncertainty. Reduced-order control, stability, multipliers, and mixed-mu. Prerequisite: ECE 6531. 3 credit hours • AE 6534, Control of AE Structures – Advanced treatment of control of flexible structures. Topics include stability of multi-degree-of-freedom systems, passive and active

	absorbers and isolation, positive real models, and robust control for flexible structures. Prerequisite: ECE 6230, ECE 6531. 3 credit hours • AE 6580, Nonlinear Control – Advanced treatment of nonlinear robust control. Lyapunov stability theory, absolute stability, dissipativity, feedback linearization, Hamilton-Jacobi-Bellman theory, nonlinear H-infinity, backstepping control, and control Lyapunov functions. Prerequisite: ECE 6550. 3 credit hours • AE 8803 THE, Nonlinear Stochastic Optimal Control 3 credit hours • ECE 6550*, Linear Systems and Controls – Introduction to linear system theory and feedback control. Topics include state space representations, controllability and observability, linear feedback control. Prerequisite: Graduate Standing. 3 credit hours • ECE 6551, Digital Controls – Techniques for analysis and synthesis of computer-based control systems. Design projects provide an understanding of the application of digital control to physical systems. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ECE 6552, Nonlinear Systems and Control – Classical analysis techniques and stability theory for nonlinear systems. Control design for nonlinear systems, including robotic systems. Includes design projects. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ECE 6553, Optimal Control and Optimization – Optimal control of dynamic systems, numerical optimization, techniques and their applications in solving optical-trajectory problems. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ECE 6554, Adaptive Control – Methods of parameter estimation and adaptive control for systems with constant or slowly varying unknown parameters. Includes MATLAB design projects emphasizing applications to physical systems. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ECE 6555, Optimal Estimation – Techniques for signal and state estimation in the presence of measurement and process noise with the emphasis on Wiener and Kalman filtering. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ECE 6559, Advanced Linear Systems – Study of multivariable linear system theory and robust control design methodologies. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ECE 6563 Networked Control and Multiagent Systems • ME 6401*, Linear Control Systems – Theory and applications of linear systems, state space, stability, feedback controls, observers, LQR, LQG, Kalman Filters. Prerequisite: ME 3015 or equivalent, or with the consent of the instructor. 3 credit hours • ME 6402, Nonlinear Control Systems – Analysis of nonlinear systems, geometric control, variable structure control, adaptive control, optimal control, applications. Prerequisite: ME 6401 or equivalent, or with the consent of the instructor. 3 credit hours • ME 6403, Digital Control Systems – Comprehensive treatment of the representation, analysis, and design of discrete-time systems. Techniques include Z- and W- transforms, direct method, control design, and digital tracking. Prerequisite: ME 3015 or equivalent, or with the consent of the instructor. 3 credit hours • ME 6404, Advanced Control System Design and Implementation – Analysis, synthesis and implementation techniques of continuous-time and real-time control systems using classical and state-space methods. Prerequisite: ME 6403 or equivalent, or with the consent of the instructor. 3 credit hours
Perception	• CS 6476*, Computer Vision – Introduction to computer vision including fundamentals of image formation, camera imaging geometry, feature detection and matching, stereo, motion estimation and tracking, image classification and scene understanding. Credit not awarded for both CS 6476 and CS 4495 or CS 4476. 3 credit hours • CS 7476, Advanced Computer Vision – Advanced topics in computer vision, which includes a

	deep dive into both the theoretical foundations of computer vision to the practical issues of building real systems that use computer vision. Credit not awarded for CS 7476 and CS 7495. 3 credit hours • CS 7616, Pattern Recognition – This course provides an introduction to the theory and practice of pattern recognition. It emphasizes unifying concepts and the analysis of real-world datasets. 3 credit hours • CS 7636, Computational Perception – Study of statistical and algorithmic methods for sensing people using video and audio. Topics include face detection and recognition, figure tracking, and audio-visual sensing. Prerequisites: CS 4641 and (CS 4495 or CS 7495) 3 credit hours • CS 7499, 3D Reconstruction and Mapping – Course focuses on multi-robot/multi-camera mapping and reconstruction. Topics range from SLAM, graphical model inferences, and understanding the practical issues regarding multi-platform reconstruction. 3 credit hours • CS 7626 Behavioral Imaging – Theory and methods for measuring, recognizing, and quantifying social and communicative behavior using video, audio, and wearable sensor data. 3 credit hours • CS 7643 Deep Learning, 3 credit hours • ECE 6255, Digital Processing of Speech Signals – The application of digital signal processing to problems in speech communication. Includes a laboratory project. Prerequisites: ECE 4270 Minimum Grade of D. 3 credit hours • ECE 6258, Digital Image Processing – An introduction to the theory of multidimensional signal processing and digital image processing, including key applications in multimedia products and services, and telecommunications. Prerequisites: ECE 4270 Minimum Grade of D. 3 credit hours • ECE 6273, Pattern Recognition – Theory and application of pattern recognition with a special application section for automatic speech recognition and related signal processing. Prerequisites: ECE 4270 Minimum Grade of D. 3 credit hours • ECE 6560, PDEs in Image Processing and Computer Vision – Mathematical foundations and numerical aspects of partial-differential equation techniques used in computer vision. Topics include image smoothing and enhancement, edge detection, morphology, and image reconstruction. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours • ME 6406*, Machine Vision – Design of algorithms for vision systems for manufacturing, farming, construction, and the service industries. Image processing, optics, illumination, feature representation. Prerequisite: Graduate Standing in engineering or related discipline. 3 credit hours
Artificial Intelligence	• CS 6601*, Artificial Intelligence – Basic concepts and methods of artificial intelligence including both symbolic/conceptual and numerical/probabilistic techniques. Prerequisites: CS 2600 • CS 7612, AI Planning – Symbolic numerical techniques that allow intelligent systems to decide how they should act in order to achieve their goals, including action and plan representation, plan synthesis and reasoning, analysis of planning algorithms, plan execution and monitoring, plan reuse and learning, and applications. Prerequisites: CS 6601 • CS 7640, Learning in Autonomous Agents – An in-depth look at agents that learn, including intelligent systems, robots, and humans. Design and implementation of computer models of learning and adaptation in autonomous intelligent agents. Prerequisites: CS 3600 or CS 4641 • CS 7641 Machine Learning – Machine learning techniques and applications. Topics include foundational issues; inductive, analytical, numerical, and theoretical approaches; and real-world applications. Prerequisites: CS 6601 • CS 7643 Deep Learning, 3 credit hours

	• CS 7648 Interactive Robot Learning, 3 credit hours. • CS 8803, Mobile Manipulation – The objective of the course is to gain knowledge of methods for design of mobile manipulation systems. The course covers all aspects of the problem from navigation and localization over kinematics and control to visual and force based perception. • CS 8803, Robot Intelligence: Planning in Action – Course covers methods for planning with symbolic, numerical, geometric and physical constraints. Topics will range from classical and stochastic planning to continuous robot domains and hybrid control of dynamic systems. • CS 8803, Robot Motion Planning, 3 credit hours. • CS 8803, Computation and the Brain • CS 7642 Reinforcement Learning • CS 8803, Statistical Techniques in Robotics • CS 8803/ECE 8803 (fall 2020 - CS 7751/ECE 7751), Probabilistic Graph Models and ML in High Dimensions • ECE 6254, Statistical Machine Learning • ECE 6556, Intelligent Control – Principles of intelligent systems and their utility in modeling, identification, and control of complex systems; neuro-fuzzy tools applied to supervisory control; hands-on laboratory experience. Prerequisites: ECE 6550 Minimum Grade of D. 3 credit hours
Human-Robot Interaction (HRI)	**HRI includes two core courses. Students are encouraged, but not required to take both HRI core courses. Students taking both core courses may use their second core class in place of an HRI elective course.** • AE 6721*, Evaluation of Human Integrated Systems – Evaluation of human integrated systems including translating research questions into measurable objectives, overview of evaluation methods and data analysis techniques applicable to such systems. 3 credit hours • CS 7633*, Human-Robot Interaction – Survey of the state of the art in HRI research, introduction to statistical methods for HRI research, research project studio. A petition has been filed for this to be added to the permanent CS curriculum and have permanent course number. 3 credit hours • CS 6455, User Interface Design and Evaluation – Qualitative empirical methods for understanding human-technology interaction. 3 credit hours • CS 6750, Human-Computer Interact – Describes the characteristics of interaction between humans and computers and demonstrates techniques for the evaluation of user-centered systems. 3 credit hours • CS 7648 Interactive Robot Learning, 3 credit hours. • CS 8803 CSR, Computational Social Robotics 3 credit hours • ISYE 6215, Human-Machine Systems – The development and use of mathematical models of human behavior are considered. Approaches from estimation theory, control theory, queuing theory, and fuzzy set theory are considered. 3 credit hours • ISYE 6224, Human-Integrated Systems – State-of-the-art research directions including supervisory control models of human command control tasks; human-computer interface in scheduling and supervision of flexible manufacturing systems. 3 credit hours • PSYC 6011, Cognitive Psychology – Survey course on human cognition including pattern recognition, attention, memory, categorization, problem solving, consciousness, decision making, intention, and the relation between mind and brain. • PSYC 6014, Sensation & Perception – This course examines how sensations and perceptions of the outside world are processed by humans, including physiological, psychophysical, ecological, and computational perspectives. 3 credit hours

	• PSYC 6017, Human Abilities – Theory, methods, and applications of research on human abilities, including intelligence, aptitude, achievement, learning, aptitude treatment interactions, information processing correlates, and measurement issues. 3 credit hours • PSYC 7101, Engineering Psych I – Basic methods used to study human-machine systems including both system analysis and human performance evaluation techniques. These methods will be applied to specific systems. 3 credit hours • PSYC 7104, Psychomotor & Cog Skill – Human capabilities and limitations for learning and performing psychomotor and cognitive skills are studied. 3 credit hours

Health and Wellness Resources

- Questions about Student Health Insurance should be directed to Jennifer White at STAMPS ((404) 894-0633).
- Graduate school can be a stressful time for students. The Georgia Tech Counseling Center and STAMPS health services offer a wide range of programs and services that can help students who may need assistance. The Georgia Tech Health Initiatives site includes information on many stress-management services available on campus (e.g., yoga, mindfulness), as well as diet and lifestyle resources.
- If you just need to talk to another graduate student who knows what you are going through, the Peer Coaching Program provides students with another way to receive support with their academic, social, and other concerns. Students are matched with a fellow Tech student who has been extensively trained to navigate mental health conversations and who is knowledgeable about campus resources.
- Additional resources on campus that are there to assist graduate students include the Women's Resource Center**,** the LGBTQIA Resource Center and the Veteran's Resource Center**.**
- Put the Georgia Tech Police number in your phone (404-894-2500) to call for any safety concerns. Call 911 for emergencies.

  All these links (and more!) are collect at one site: GT United. **Please bookmark this site!** The bottom line: if you need help with anything, please ask! There are many resources available to ensure your Ph.D. experience is all you want it to be.