ROBOTICS AND AUTONOMOUS SYSTEMS, MASTER OF SCIENCE

Admission Requirements

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements (https://e-catalogue.jhu.edu/engineering/engineering-professionals/admission-requirements/) section. In addition, applicants for the Master of Science in Robotics and Autonomous Systems will likely have prior educational experience that includes an undergraduate or higher major in mechanical engineering, electrical engineering, computer science, information science, mathematics, systems engineering, basic sciences, or the equivalent. The applicant's prior education must include the following courses:

- Calculus through Multivariable Calculus;
- Linear Algebra;
- Differential Equations;
- Programming (such as C++, Java, or Python)

Students must have taken courses in or demonstrated proficiency in mathematics, engineering, and software development. Applicants whose prior education does not include the courses listed above may still be enrolled under provisional status, followed by full admission once they have completed the missing courses. Missing courses may be completed with Johns Hopkins Engineering (some prerequisites beyond calculus are available) or at another regionally accredited institution. These courses do not count toward the degree requirements. Admitted students typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Program Requirements

In order to earn a Master of Science in Robotics and Autonomous Systems, the student must complete ten courses within five years. A focus area is required. The curriculum consists of four core courses, three courses from one of the focus areas of the Robotics and Autonomous Systems program, and three courses of electives from any Engineering for Professionals program. Three courses must be taken at the 700-level. One or more core courses can be waived by the student's advisor if a student has received an A or B in equivalent graduate courses. In this case, the student may replace the waived core courses with the same number of other graduate Robotics and Autonomous Systems courses and may take these courses after all remaining core course requirements have been satisfied. Only one C-range grade (C+, C, or C–) can count toward the master's degree.

Provisional Courses

Code	Title	Credits
Undergraduate Courses (or approved equivalent) [1]		**Credits**
EN.605.201	Introduction to Programming Using Java	3
or EN.605.206	Introduction to Programming Using Python	
or EN.605.207	Introduction to Programming Using C++	
EN.625.250	Multivariable Calculus and Complex Analysis	3
EN.625.251	Introduction to Ordinary and Partial Differential Equations	3
EN.625.252	Linear Algebra and Its Applications	3

[1] Applicants whose prior education does not include the courses listed under Admission Requirements may enroll under provisional status, followed by full admission once they have completed the missing courses. All courses are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

Core Courses

Code	Title	Credits
A total of 4 core courses are required [2]		**Credits**
EN.685.621	Algorithms for Data Science	3
EN.535.641	Mathematical Methods For Engineers	3
Followed by these 2 courses		**Credits**
EN.605.613	Introduction to Robotics	3
EN.535.630	Kinematics & Dynamics of Robots	3

[2] One or more core courses can be waived by the student's advisor if a student has received an A or B in equivalent graduate courses. In this case, the student may replace the waived core courses with the same number of other graduate courses and may take these courses after all remaining core course requirements have been satisfied.

Course by Focus Area

- Autonomous Systems (p. 1)
- Dynamics, Navigation, Decision, and Control (p. 2)
- General Robotics (p. 2)
- Human-Robot and Robot-Robot Teaming (p. 2)
- Perception and Cognitive Systems (p. 3)

Autonomous Systems

Autonomous systems include both kinetic robotic systems as well as non-kinetic algorithms that perceive themselves and their world, interpret their perceptions and represent them using higher level symbology, develop and compose courses of action to accomplish their goals, execute on their goals, and check on current state to determine if anything has changed and how to respond accordingly. Autonomous systems may work independently or in concert with other autonomous systems. Autonomous operate over a continuum of autonomy ranging from systems that are remotely controlled by a human operator to fully autonomous systems that complete their missions without human oversight.

Students pursuing the Autonomous Systems Focus Area must take three of the following courses.

Code	Title	Credits
Courses		**Credits**
EN.665.645	Artificial Intelligence for Robotics	3
EN.665.681	Application of Sensing Systems	3
EN.665.684	Capstone Robotic Systems Development	3
EN.525.637	Foundations of Reinforcement Learning	3
EN.605.636	Autonomic Computing [3]	3
EN.605.645	Artificial Intelligence [3]	3

EN.605.647	Neural Networks	3
EN.605.649	Principles and Methods in Machine Learning [3]	3
EN.605.715	Software Development for Real-Time Embedded Systems	3
EN.605.716	Modeling and Simulation of Complex Systems	3
EN.605.742	Deep Neural Networks	3
EN.605.746	Advanced Machine Learning	3
EN.635.673	Protecting Critical Infrastructure Against Cyber Attacks	3
EN.635.782	Ethics in Intelligent Systems	3
EN.635.792	Entrepreneurship, Innovation, and Corporate Success	3
EN.645.742	Management of Complex Systems	3
EN.695.611	Embedded Computer Systems-Vulnerabilities, Intrusions, and Protection Mechanisms	3
EN.695.634	Intelligent Vehicles: Cybersecurity for Connected and Autonomous Vehicles	3
EN.695.637	Introduction to Assured AI and Autonomy	3
EN.695.715	Assured Autonomy	3
EN.705.612	Values and Ethics in Artificial Intelligence	3

[3] This course requires Data Structures.

Dynamics, Navigation, Decision, and Control

Robots and many autonomous systems have physical embodiment that enables them to move through their environment and are often capable of performing useful work that actively modifies the state of their natural and built environment. The Dynamics, Navigation, Decision, and Control Focus Area is designed to enable a student to specialize in these closely related areas: **Dynamics** seeks to elucidate the physics of robot motion and its physical interaction with the world, **Navigation** seeks to answer the question "Where am I?" It is how a robot localizes its position and velocity in relation to other robots and its environment. **Decision and Control** is how robots and autonomous systems use their actuators (propulsors, wheels, legs, wings, thrusters, control surfaces) to make decisions on future motion and to control those motions and interactions.

Students pursuing the Dynamics, Navigation, Decision, and Control Focus Area must take three of the following courses.

Code	Title	Credits
Courses		**Credits**
EN.665.645	Artificial Intelligence for Robotics	3
EN.665.681	Application of Sensing Systems	3
EN.665.684	Capstone Robotic Systems Development	3
EN.525.610	Microprocessors for Robotic Systems	3
EN.525.637	Foundations of Reinforcement Learning	3
EN.525.642	FPGA Design Using VHDL	3
EN.525.645	Modern Navigation Systems	3
EN.525.661	UAV Systems and Control	3
EN.525.728	Detection & Estimation Theory	3
EN.525.777	Control System Design Methods	3
EN.535.622	Robot Motion Planning	3
EN.535.630	Kinematics & Dynamics of Robots	3
EN.535.642	Control Systems for Mechanical Engineering Applications	3
EN.535.645	Digital Control and Systems Applications	3
EN.535.724	Dynamics of Robots and Spacecraft	3
EN.535.741	Optimal Control and Reinforcement Learning	3
EN.605.716	Modeling and Simulation of Complex Systems	3
EN.605.724	Applied Game Theory	3
EN.605.745	Reasoning Under Uncertainty	3
EN.625.615	Introduction to Optimization	3
EN.625.741	Game Theory	3
EN.625.743	Stochastic Optimization & Control	3
EN.635.782	Ethics in Intelligent Systems	3

General Robotics

The General Robotics Focus Area is designed to accommodate the student who seeks a broad knowledge in robotics and autonomous systems, or who seeks a focus area unique to their needs in interests in robotics and autonomous systems. In this focus area, a student may choose any three courses listed in the other four focus areas, and three elective courses from among all Engineering for Professionals program (EP) courses. The student must review their course of study plan with their EP advisor and must receive their advisor's approval of the proposed course of study.

Human-Robot and Robot-Robot Teaming

Autonomous vehicle, smart city, robotic, medical, and industrial systems face unprecedented challenges because they interact with a complex ecosystem of intelligent systems whose behaviors are emergent and unpredictable. Further, intelligent systems face the nuanced challenge of acting in fair, ethical, and socially acceptable ways as they team with humans to augment, rather than replace, them. It is critical to develop these systems with the goal of working smoothly with humans and other autonomous systems to maximize their utility and acceptance.

Students pursuing the Human-Robot and Robot-Robot Teaming Focus Area must take three of the following courses.

Code	Title	Credits
Courses		**Credits**
EN.665.645	Artificial Intelligence for Robotics	3
EN.665.681	Application of Sensing Systems	3
EN.665.684	Capstone Robotic Systems Development	3
EN.525.747	Speech Processing	3
EN.525.786	Human Robotics Interaction	3
EN.535.691	Haptic Interface Design	3
EN.535.782	Haptic Applications	3
EN.585.783	Introduction to Brain-Computer Interfaces	3
EN.605.646	Natural Language Processing	3
EN.635.661	Principles of Human Computer Interaction	3
EN.635.782	Ethics in Intelligent Systems	3
EN.645.650	Foundations of Human Systems Engineering	3
EN.645.651	Integrating Humans and Technology	3
EN.645.755	Methods in Human-System Performance Measurement and Analysis	3
EN.705.612	Values and Ethics in Artificial Intelligence	3

EN.705.640	Cognitive and Behavioral Foundations for Artificial Intelligence	3

Perception and Cognitive Systems

Robots and autonomous systems typically contain sensory systems that generate immense quantities of raw data representing Images, video, depth-maps, optical flow, movements, etc. Advanced perception and cognitive systems interpret the raw data of sensor signals and transform them into a high-level symbolic and quantitative understanding of its environment. Reasoning systems and other advanced artificial intelligence and machine learning methods interpret the environment in context with its goals to develop plans for performing complex tasks. Students pursuing the Perception and Cognitive Systems Focus Area must take three of the following courses.

Code	Title	Credits
Credits		**Credits**
EN.665.645	Artificial Intelligence for Robotics	3
EN.665.681	Application of Sensing Systems	3
EN.665.684	Capstone Robotic Systems Development	3
EN.525.637	Foundations of Reinforcement Learning	3
EN.525.724	Introduction to Pattern Recognition	3
EN.525.728	Detection & Estimation Theory	3
EN.525.733	Deep Learning for Computer Vision	3
EN.525.746	Image Engineering	3
EN.525.747	Speech Processing	3
EN.525.748	Synthetic Aperture Radar	3
EN.535.741	Optimal Control and Reinforcement Learning	3
EN.605.624	Logic: Systems, Semantics, and Models	3
EN.605.646	Natural Language Processing	3
EN.605.647	Neural Networks	3
EN.605.649	Principles and Methods in Machine Learning [3]	3
EN.605.742	Deep Neural Networks	3
EN.605.746	Advanced Machine Learning	3
EN.635.782	Ethics in Intelligent Systems	3
EN.705.612	Values and Ethics in Artificial Intelligence	3

[3] This course requires Data Structures.

Independent Study

Code	Title	Credits
Courses		**Credits**
EN.665.801	Independent Study in Robotics & Autonomous Systems I	3
EN.665.802	Independent Study in Robotics & Autonomous Systems II	3