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 prerequisites:

- 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 prerequisites listed above may still be enrolled under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (some prerequisites beyond calculus are available) or at another regionally accredited institution. These prerequisite 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. 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 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.

Undergraduate Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>EN.605.201</td>
<td>Introduction to Programming Using Java</td>
<td>3</td>
</tr>
<tr>
<td>or EN.605.206</td>
<td>Introduction to Programming Using Python</td>
<td>3</td>
</tr>
<tr>
<td>EN.625.250</td>
<td>Multivariable Calculus and Complex Analysis</td>
<td>3</td>
</tr>
</tbody>
</table>

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

Core Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.625.251</td>
<td>Introduction to Ordinary and Partial Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>EN.625.252</td>
<td>Linear Algebra and Its Applications</td>
<td>3</td>
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</tbody>
</table>


A total of 4 core courses are required 2

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>EN.685.621</td>
<td>Algorithms for Data Science</td>
<td>3</td>
</tr>
<tr>
<td>EN.535.641</td>
<td>Mathematical Methods For Engineers</td>
<td>3</td>
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</table>

Followed by these 2 courses

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<tr>
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<tbody>
<tr>
<td>EN.605.613</td>
<td>Introduction to Robotics</td>
<td>3</td>
</tr>
<tr>
<td>EN.535.630</td>
<td>Kinematics &amp; Dynamics of Robots</td>
<td>3</td>
</tr>
</tbody>
</table>

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. 2)

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.

<table>
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<tr>
<td>EN.525.637</td>
<td>Foundations of Reinforcement Learning</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.636</td>
<td>Autonomic Computing</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.645</td>
<td>Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.647</td>
<td>Neural Networks</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.649</td>
<td>Principles and Methods in Machine Learning</td>
<td>3</td>
</tr>
</tbody>
</table>
Students pursuing the Dynamics, Navigation, Decision, and Control Focus Area is designed to enable a student to specialize in 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.

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<td>Modeling and Simulation of Complex Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.724</td>
<td>Applied Game Theory</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.745</td>
<td>Reasoning Under Uncertainty</td>
<td>3</td>
</tr>
<tr>
<td>EN.625.615</td>
<td>Introduction to Optimization</td>
<td>3</td>
</tr>
<tr>
<td>EN.625.741</td>
<td>Game Theory</td>
<td>3</td>
</tr>
<tr>
<td>EN.625.743</td>
<td>Stochastic Optimization &amp; Control</td>
<td>3</td>
</tr>
<tr>
<td>EN.635.782</td>
<td>Ethics in Intelligent Systems</td>
<td>3</td>
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</table>

**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.

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**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.

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<td>Applied Game Theory</td>
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<td>EN.605.745</td>
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<td>Introduction to Optimization</td>
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<td>EN.625.741</td>
<td>Game Theory</td>
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<tr>
<td>EN.625.743</td>
<td>Stochastic Optimization &amp; Control</td>
<td>3</td>
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<tr>
<td>EN.635.782</td>
<td>Ethics in Intelligent Systems</td>
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</tr>
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</table>

**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.

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>EN.665.681</td>
<td>Application of Sensing Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.637</td>
<td>Foundations of Reinforcement Learning</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.724</td>
<td>Introduction to Pattern Recognition</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.728</td>
<td>Detection &amp; Estimation Theory</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.733</td>
<td>Deep Learning for Computer Vision</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.746</td>
<td>Image Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.747</td>
<td>Speech Processing</td>
<td>3</td>
</tr>
<tr>
<td>EN.525.748</td>
<td>Synthetic Aperture Radar</td>
<td>3</td>
</tr>
<tr>
<td>EN.535.741</td>
<td>Optimal Control and Reinforcement Learning</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.624</td>
<td>Logic: Systems, Semantics, and Models</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.646</td>
<td>Natural Language Processing</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.647</td>
<td>Neural Networks</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.649</td>
<td>Principles and Methods in Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.742</td>
<td>Deep Neural Networks</td>
<td>3</td>
</tr>
<tr>
<td>EN.605.746</td>
<td>Advanced Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>EN.635.782</td>
<td>Ethics in Intelligent Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.705.612</td>
<td>Values and Ethics in Artificial Intelligence</td>
<td>3</td>
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</table>

3 This course requires Data Structures.

**Independent Study**

<table>
<thead>
<tr>
<th>Code</th>
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</tr>
</thead>
<tbody>
<tr>
<td>EN.665.801</td>
<td>Independent Study in Robotics &amp; Autonomous Systems I</td>
<td>3</td>
</tr>
<tr>
<td>EN.665.802</td>
<td>Independent Study in Robotics &amp; Autonomous Systems II</td>
<td>3</td>
</tr>
</tbody>
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