Robotics and Computational Sensing

https://www.lcsr.jhu.edu/Main_Page

Laboratory for Computational Sensing and Robotics

The Laboratory for Computational Sensing and Robotics (LCSR) is one of the most technologically advanced robotics research centers worldwide, and is an international leader in the areas of medical robotics, autonomous systems, and bio-inspiration. Within Johns Hopkins, a premiere research university, the LCSR is a hub for innovative and interdisciplinary robotics engineering, research, and development. The LCSR brings a core group of scholars and students from the Whiting School of Engineering together with researchers from the Johns Hopkins School of Medicine, the Bloomberg School of Public Health, the Krieger School of Arts and Sciences, the Johns Hopkins University Applied Physics Laboratory and the Kennedy Krieger Institute to focus on the common purpose of creating knowledge and fostering innovation.

Minor in Robotics

The field of robotics integrates sensing, information processing, and movement to accomplish specific tasks in the physical world. As such, it encompasses several topics, including mechanics and dynamics, kinematics, sensing, signal processing, control systems, planning, and artificial intelligence. Applications of these concepts appear in many areas including medicine, manufacturing, space exploration, disaster recovery, ordinance disposal, deep-sea navigation, home care, and home automation.

The faculty of the Laboratory for Computational Sensing and Robotics (LCSR), in collaboration with the academic departments and centers of the Whiting School of Engineering, offers a robotics minor in order to provide a structure in which undergraduate students at Johns Hopkins University can advance their knowledge in robotics while receiving recognition on their transcript for this pursuit. The minor is not “owned” by any one department, but rather it is managed by the LCSR itself. Any student from any department within the university can work toward the minor.

Robotics is fundamentally integrative and multidisciplinary. Therefore, any candidate for the robotics minor must develop a set of core skills that cut across these disciplines, as well as obtain advanced supplementary skills.

Please visit http://lcsr.jhu.edu/computer-integrated-surgery-minor/ for current course listings and full minor policies.

Core Skills Include the Following

- Robot kinematics and dynamics (R)
- Systems theory, signal processing and control (S)
- Computation and sensing (C)

Supplementary advanced skills may be obtained in specialized applications, such as space, medicine, or marine systems; or in one of the three core areas listed above.

The full minor course listing, provided below and available at https://lcsr.jhu.edu/robotics-minor/, specifies which courses fulfill these requirements. Note that ALL core areas must be covered, but that ANY advanced/supplementary courses can be chosen from the list. This allows students to strike a balance between breadth and depth.

Requirements

Undergraduates qualify for the minor provided they have taken at least 18 credits (at the 300-level or above, with a C- or above) from an approved list of courses available below and at https://lcsr.jhu.edu/robotics-minor/ with the following requirements and restrictions:

- Between 6 and 12 credits chosen to cover the three core skills (R, S, C).
- At least 6 credits chosen from advanced supplementary skills (Sup).
- At least 3 credits of the 18 must be a laboratory course (Lab) (at least 15 hours of laboratory time that includes working with physical hardware and/or real data).

At most 3 credits of the 18 can be an independent research or individual study with a faculty member on the list of approved faculty advisers.

- At least 6 credits must be primarily listed in a department other than the student’s home department (it is acceptable if such a course is cross-listed in the student’s home department).
- At most one course up to 3 credits (including independent research or individual study) may be taken S/U, but all other courses must be taken for a letter grade.

Graduate levels of the same course may be substituted for the undergraduate levels listed below without additional permissions.

<table>
<thead>
<tr>
<th>Course Number/Title</th>
<th>Lab</th>
<th>R</th>
<th>S</th>
<th>C</th>
<th>Sup</th>
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<tbody>
<tr>
<td>EN.530.353 Control Systems</td>
<td></td>
<td>X</td>
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<tr>
<td>EN.520.412 Machine Learning for Signal Processing</td>
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<td>X</td>
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<tr>
<td>EN.520.414 Image Processing &amp; Analysis</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.520.415 Image Process &amp; Analysis II</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.520.424 FPGA Synthesis Lab</td>
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<td>X</td>
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<tr>
<td>EN.520.432 Medical Imaging Systems</td>
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<td>X</td>
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<tr>
<td>EN.520.433 Medical Image Analysis</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.520.435 Digital Signal Processing</td>
<td>X</td>
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<tr>
<td>EN.520.448 Electronics Design Lab</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.520.454 Control Systems Design X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.530.343 Design and Analysis of Dynamical Systems</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.530.420 Robot Sensors/Actuators</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.530.421 Mechatronics</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.530.424 Dynamics of Robots and Spacecraft</td>
<td>X</td>
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<tr>
<td>EN.530.426 Robot Devices, Kinematics, Dynamics, and Control</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EN.530.476 Locomotion in Mechanical and Biological Systems</td>
<td>X</td>
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<tr>
<td>EN.530.486 Mechanics of Locomotion</td>
<td>X</td>
<td>X</td>
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Advising

- All students interested in the minor are required to make an appointment with Alison Morrow in LCSR to be assigned to a minor adviser to receive guidance about the program. Email: Alison.morrow@jhu.edu
- When possible, you will be assigned an adviser in your department (though this is not required).
- Students who decide to pursue the minor should also review their academic transcript with their minor adviser to ensure they will be able to complete the requirements.
- Fill out and submit an Add Minor form (which can be obtained from the registrar’s office).
- Complete the Requirements Checklist tables in the Check Out sheet, downloadable from https://lcsr.jhu.edu/robotics-minor/. You should meet with your minor adviser periodically (at least once per year), bringing a copy of this form for review.
- During your senior year, you must also note the Robotics Minor on your Application for Graduation.
- When all requirements have been completed, take the completed form to the Alison Morrow for review and signature.

Undergraduates interested in completing the minor must be assigned a minor adviser. The adviser is responsible for helping the student choose courses and helps to ensure all requirements for the minor are met. The minor advisers are listed on the Robotics Minor website (https://lcsr.jhu.edu/robotics-minor/).

### MINOR GOVERNANCE

The minor is continually monitored by a standing governance/oversight committee, currently comprised of the following faculty:

- Noah Cowan, Program Coordinator
- Greg Chirikjian, Program Committee Member
- Ralph Etienne-Cummings, Program Committee Member
- Gregory D. Hager, Program Committee Member
- Russ Taylor, Program Committee Member

The oversight of this minor, including curricular updates, falls to this committee. The minor is managed by the [faculty of the] Laboratory for Computational Sensing and Robotics (LCSR) [in collaboration with the academic departments and centers of the Whiting School of Engineering].

The minor is managed by faculty of the LCSR in collaboration with academic departments and centers of the Whiting School of Engineering. If you have suggestions / questions regarding the minor, please direct them to Prof. Noah Cowan.

### Minor in Computer Integrated Surgery

The Whiting School of Engineering offers a minor in Computer Integrated Surgery (CIS) for full-time, undergraduate students at Johns Hopkins. The minor is particularly well suited for students interested in computer integrated surgery issues who are majoring in a variety of disciplines including biomedical engineering, computer science, computer engineering, electrical engineering, and mechanical engineering. The minor provides formal recognition of the depth and strength of a student’s knowledge of the concepts fundamental to CIS beyond the minimal requirements of his/her major.

In order to minor in CIS, a student will require a minor adviser from the Engineering Research Center in Computer Integrated Surgical Systems and Technology (CISST ERC) in the Laboratory for Computational Sensing and Robotics. Current faculty members available as advisers include Professors Russell Taylor (CS), Greg Hager (CS), Jerry Prince (ECE), Ralph Etienne-Cummings (ECE), Louis Whitcomb (ME), Noah Cowan (ME), Marin Kobilarov (ME), Peter Kazanzides (CS), Iulian Iordachita (ME), and Emad Boctor (Radiology).

To satisfy the requirements for the minor in CIS, a student must have a fundamental background in computer programming and computer science, sufficient mathematical background, and also take a minimum of six courses (with a total of at least 18 credits, earning at least a C- in each course) directly related to the concepts relevant to CIS. These six CIS courses must include two fundamental CIS core courses, which provide the student with the fundamental basis for CIS, and four approved upper-level courses (300-level or above) to allow the student to pursue an advanced CIS topic in depth. The additional four upper-level courses must include at least one course designated as an “imaging” course or one course designated as a “robotics” course, as discussed below.

Undergraduates interested in completing the minor must be assigned a minor adviser. The adviser is responsible for helping the student choose courses and helping to ensure all requirements for the minor are met. The minor advisers are listed on the Robotics Minor website (https://lcsr.jhu.edu/robotics-minor/).

### Required Fundamental Computer Science Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>EN.601.226</td>
<td>Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>EN.601.107</td>
<td>Introductory Programming in Java</td>
<td>3</td>
</tr>
</tbody>
</table>

Or equivalent experience determined by your CIS minor adviser.
**Robotics M.S.E. Program**

For complete and up-to-date M.S.E. information, visit [https://lcsr.jhu.edu/mse](https://lcsr.jhu.edu/mse).

The Master of Science in Engineering in Robotics (Robotics MSE) program at Johns Hopkins University is designed to advance interdisciplinary robotics knowledge in students coming from a wide variety of engineering, scientific, and mathematical backgrounds.

Johns Hopkins University recognizes the growing need in industry for engineers with the broad multi-disciplinary training and fundamental knowledge needed to develop and deploy advanced robotics systems that function effectively in the real world.

Johns Hopkins University’s broad interdisciplinary approach to robotics research makes it uniquely situated to offer such a comprehensive program. The Laboratory for Computational Sensing and Robotics (LCSR), with its reputation as one of the top robotics research sites in the world, particularly in the area of medical robotics, is pleased to offer this MSE in Robotics.

**Program Goals**

- To provide students with multi-disciplinary engineering education and training that will enable them to develop and deploy innovative advanced robotics systems that function effectively in real-world applications.
- To develop students’ ability to relate individual technical and design elements to the functioning of complete engineered robotic systems.
- To develop students’ ability to work effectively within and to lead multi-disciplinary teams.
- To provide students with a basis for life-long learning and professional growth.

**Application Requirements for the M.S.E. in Robotics degree**

- Bachelor’s degree in engineering, science, or math. (Or demonstrated knowledge or accomplishment in these fields)
- Statement of Purpose – in your short statement of purpose please take a couple of sentences to explain/answer the following:
  - Why are you interested in doing an MSE in Robotics? No need to over-think this: it is fine if it is as simple as wanting to get a job in this field!
  - Are you interested in a specific Robotics Track? See the Robotics MSE website for more information on tracks.
- Transcript
- Three letters of reference
- Graduate Record Examination (GRE). Current JHU students may request that this requirement be waived. Such requests will be judged on a case-by-case basis.
- IELTS or TOEFL for international applicants. Please note: while the Robotics program accepts both the TOEFL and the IELTS tests, we strongly prefer the IELTS.
- Three letters of reference
- $75.00 Application fee
- The Office of Graduate Admissions and Enrollment strongly recommends you submit a professional evaluation from one of the recommended resources (more information here [http://grad.jhu.edu/apply/international-students]) for any academic work completed outside the USA. At this time, however, LCSR does not require the evaluation for the Robotics MSE application package.

To apply, please fill out the application and submit the required documents here [https://app.applyyourself.com/AYApplicantLogin/FL_ApplicantLogin.asp?id=jhu-grad].

In making its final decisions, the Admissions Committee will consider the combination of professional knowledge, academic excellence, letters of reference, and the statement of purpose, as well as GRE, TOEFL, and IELTS scores of the applicants.
M.S.E. Program Prerequisites

Math and Physics Proficiency Prerequisites

Proficiency in undergraduate mathematics and physics is expected for all M.S.E. students in the robotics program.

This includes proficiency in:

- Multivariable integral and differential calculus;
- Linear algebra;
- Ordinary differential equations;
- Physics – undergraduate calculus-based mechanics, electricity, and magnetism;
- Probability and statistics.

Proficiency will be assumed in the prerequisites for the core courses.

Computing Proficiency Prerequisites

Proficiency in computer programming is expected for all M.S.E. students in the robotics program.

This includes proficiency in:

- Basic numerical methods using existing programming environments;
- The ability to write well-structured and documented programs in a standard programming language such as C++, Java, or MATLAB.

M.S.E. Degree Requirements

All incoming M.S.E. students will be assigned an M.S.E. Academic Advisor.

- Course Requirements:
  - Course Option: 10 credit-bearing courses that total at least 30 credit-hours.
  - Essay Option: 8 credit-bearing courses that total at least 24 credit-hours and a Master’s Essay supervised by a WSE faculty member who has been approved by the Robotics M.S.E. Curriculum Committee to serve as a faculty advisor.

At least 6 of these courses must be at the graduate level as defined by the offering department/center. All courses counted toward the M.S.E. degree requirements must be at the 400 level or above. Any dual listed courses (i.e. listed at both the 600 and 400 level) must be taken at the 600 level. All courses counting towards the foundation, track, or elective requirements must be for a letter grade (i.e. no pass/fail). Any exceptions must be approved in writing by your academic advisor and the LCSR Education Director. Non-credit and one-credit courses such as the weekly seminar courses offered by LCS may not count toward this course requirement.

- Foundation Course Requirements: Two core courses and a weekly seminar course.

- Track Course Requirement: Four courses fulfilling one of the following track requirements (see website for track course listings):
  - Medical Robotics and Computer Integrated Surgical Systems (has special track requirements, please see website)
  - Perception and Cognitive Systems
  - Automation Science and Engineering
  - Control and Dynamical Systems
  - BioRobotics
  - General Robotics

Courses counted toward the track requirement may not be used to satisfy the elective requirement.

- Elective Course Requirement: Four courses, or two courses and a M.S.E. Essay, fulfilling the elective requirement. Courses may be any engineering or quantitative (designated E or Q in the course catalog) course, subject to the degree requirement limitations, as approved by the student’s M.S.E. academic advisre. Courses counted toward the elective requirement may not be used to satisfy the track requirements.

- Academic Ethics: online tutorial required for all incoming M.S.E. students (EN.500.603)
- AS.360.625 Responsible Conduct of Research (online): Online tutorial required for all incoming MSE students.
- AS.360.625 Responsible Conduct of Research (in-person): may be required for certain research projects. More information: (http://eng.jhu.edu/wse/page/conduct-of-research-training/)
- EN.500.601 Research Laboratory Safety: required for all incoming M.S.E. students.
- Course Grade Requirement: A course is satisfactorily completed if a grade from A+ to C- is obtained. No more than one C+, C, or C- can be counted toward the degree requirements. A grade of D or F or second C+, C, or C- grade results in probation. A second D or F, or a third C+, C, or C- grade typically results in termination from the program.

- Transfer Courses: Standard WSE policy and limitations on M.S.E. transfer credits apply (http://engineering.jhu.edu/graduate-studies/academic-policies-procedures-graduate/). In addition, use of each transfer course toward satisfaction of a specific Robotics M.S.E. degree requirement must be approved in writing by both the student’s faculty advisor and the Robotics M.S.E. Curriculum Committee.
- Double Counting: Standard WSE policy and limitations on double counting apply (http://engineering.jhu.edu/graduate-studies/academic-policies-procedures-graduate/).
- Duration: Students must complete degree within 5 years from matriculation in the M.S.E. program. An university-approved leave of absence does not count toward this limit.
- Graduate Research Courses: No more than one 1-semester or 3 credits of a graduate research course (e.g., EN.530.600 MSE Graduate Research) may be counted toward degree requirements.
- No more than 2 WSE Engineering for Professionals (EP) Courses may count toward the M.S.E. degree elective requirements. All EP courses must be approved in writing by the student’s faculty advisor.
- Residency Requirement: Minimum residency of two full-time academic semesters at WSE (note that summer and intersession terms do not count towards this requirement).

For complete and up-to-date M.S.E. information, visit https://lcsr.jhu.edu/mse/

Courses

AS.110.106. Calculus I (Biology and Social Sciences). 4.0 Credits.
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, introduction to differential equations, functions of several variables, linear systems, applications for systems of linear differential equations, probability distributions. Many applications to the biological and social sciences will be discussed.
Instructor(s): B. Smithling; X. Zheng
Area: Quantitative and Mathematical Sciences.
AS.110.107. Calculus II (For Biological and Social Science). 4.0 Credits. Differential and integral Calculus. Includes analytic geometry, functions, limits, integrals and derivatives, introduction to differential equations, functions of several variables, linear systems, applications for systems of linear differential equations, probability distributions. Applications to the biological and social sciences will be discussed, and the courses are designed to meet the needs of students in these disciplines.
Instructor(s): L. Sun
Area: Quantitative and Mathematical Sciences.

AS.110.108. Calculus I. 4.0 Credits. Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor’s theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the courses are designed to meet the needs of students in these disciplines.
Instructor(s): Staff
Area: Quantitative and Mathematical Sciences.

AS.110.109. Calculus II (For Physical Sciences and Engineering). 4.0 Credits. Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor’s theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the courses are designed to meet the needs of students in these disciplines.
Instructor(s): Y. Wang
Area: Quantitative and Mathematical Sciences.

AS.110.202. Calculus III. 4.0 Credits. Calculus of functions of more than one variable: partial derivatives, and applications; multiple integrals, line and surface integrals; Green’s Theorem, Stokes’ Theorem, and Gauss’ Divergence Theorem.
Prerequisites: Grade of C- or better in AS.110.107 OR AS.110.109 OR AS.110.201 OR AS.110.212 OR AS.110.302, or a 5 or better on the AP BC exam.
Instructor(s): E. Riehl
Area: Quantitative and Mathematical Sciences.

AS.110.211. Honors Multivariable Calculus. 4.0 Credits. This course includes the material in AS.110.202 with some additional applications and theory. Recommended for mathematically able students majoring in physical science, engineering, or especially mathematics. AS.110.211-AS.110.212 used to be an integrated yearlong course, but now the two are independent courses and can be taken in either order.
Prerequisites: Grade of C- or better in (AS.110.201 or AS.110.212)
Instructor(s): X. Zheng
Area: Quantitative and Mathematical Sciences.

EN.500.745. Seminar in Computational Sensing and Robotics. 1.0 Credit. Seminar series in robotics. Topics include: Medical robotics, including computer-integrated surgical systems and image-guided intervention. Sensor based robotics, including computer vision and biomedical image analysis. Algorithmic robotics, robot control and machine learning. Autonomous robotics for monitoring, exploration and manipulation with applications in home, environmental (land, sea, space), and defense areas. Biorobotics and neuromechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems. Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.
Instructor(s): L. Whitcomb; P. Kazanzides.

EN.520.353. Control Systems. 3.0 Credits. Modeling, analysis, and an introduction to design for feedback control systems. Topics include state equation and transfer function representations, stability, performance measures, root locus methods, and frequency response methods (Nyquist, Bode).
Prerequisites: Prereqs: EN.530.343 AND EN.520.214
Instructor(s): E. Mallada Garcia
Area: Engineering.

EN.520.414. Image Processing & Analysis. 3.0 Credits. The course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. Topics include elements of visual perception, sampling and quantization, image transforms, image enhancement, color image processing, image restoration, image segmentation, and multiresolution image representation. Laboratory exercises demonstrate key aspects of the course.
Prerequisites: EN.520.214.; Students may earn credit for EN.520.614 or EN.520.414, but not both.
Instructor(s): J. Goutsias
Area: Engineering.

EN.520.415. Image Process & Analysis II. 3.0 Credits. This course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by morphological image processing and analysis, image representation and description, image recognition and interpretation.
Prerequisites: Students may earn credit for EN.520.615 or EN.520.415, but not both.; EN.520.414
Instructor(s): J. Goutsias
Area: Engineering.
EN.520.427. Product Design Lab. 3.0 Credits.
This project-based course is designed to help students learn how to turn their ideas into commercial products. In the first half of the course, emphasis will be placed on the product development process: student teams will gradually build up a complete "contract book" including a mission statement, competitive analysis, patent review, product specifications, system schematics, economic analysis, development schedule, etc. In the second half of the course, each team will be expected to implement its design and demonstrate a prototype of their product's core functionality. At the end of the semester, a final written report will be submitted in the form of a utility patent. Students are encouraged to take this course in conjunction with "Electronics Design Lab (ECE 520.448)" in the Spring semester and leverage the groundwork developed here to enable production of a fully functional and marketable prototype by the end of the academic year.
Instructor(s): I. Gannot; S. Ramesh
Area: Engineering.

EN.520.432. Medical Imaging Systems. 3.0 Credits.
This course provides students with an introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality from a signals and systems perspective, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Students will additionally engage in hands-on activities to reconstruct medical images from raw data.
Prerequisites: Student may earn credit for EN.520.632 or EN.520.432, but not both.;EN.580.222 OR EN.520.214
Instructor(s): M. Bell
Area: Engineering.

EN.520.433. Medical Image Analysis. 3.0 Credits.
This course covers the principles and algorithms used in the processing and analysis of medical images. Topics include, interpolation, registration, enhancement, feature extraction, classification, segmentation, quantification, shape analysis, motion estimation, and visualization. Analysis of both anatomical and functional images will be studied and images from the most common medical imaging modalities will be used. Projects and assignments will provide students experience working with actual medical imaging data.
Prerequisites: EN.550.310 OR EN.550.311 OR EN.560.348
Instructor(s): J. Prince
Area: Engineering.

EN.520.435. Digital Signal Processing. 3.0 Credits.
Methods for processing discrete-time signals. Topics include signal and system representations, z- transforms, sampling, discrete Fourier transforms, fast Fourier transforms, digital filters.
Prerequisites: EN.520.214.;Students may receive credit for EN.520.435 or EN.520.635, but not both.
Instructor(s): H. Weinert
Area: Engineering.

EN.520.448. Electronics Design Lab. 3.0 Credits.
An advanced laboratory course in which teams of students design, build, test and document application specific information processing microsystems. Semester long projects range from sensors/actuators, mixed signal electronics, embedded microcomputers, algorithms and robotics systems design. Demonstration and documentation of projects are important aspects of the evaluation process. Recommended: EN.600.333, EN.600.334, EN.520.214, EN.520.216, EN.520.349, EN.520.372, EN.520.490 or EN.520.491.
Prerequisites: (EN.520.230 OR EN.520.213) AND (AS.110.108 AND AS.110.109 AND AS.171.101) AND EN.520.142
Instructor(s): P. Julian.

EN.520.454. Control Systems Design. 3.0 Credits.
Classical and modern control systems design methods. Topics include formulation of design specifications, classical design of compensators, state variable and observer based feedback. Computers are used extensively for design, and laboratory experiments are included.
Prerequisites: Students may earn credit for EN.520.654 or EN.520.454, but not both.
Instructor(s): P. Iglesias
Area: Engineering.

EN.520.491. CAD Design of Digital VLSI Systems I (Juniors/Seniors). 3.0 Credits.
Juniors and Seniors Only.
Prerequisites: Student may take EN.520.491 or EN.520.691, but not both.;AS.110.109 AND AS.171.102 AND EN.520.142 AND EN.520.142 AND (EN.520.230 OR (EN.520.213 AND EN.520.345))
Instructor(s): R. Etienne Cummings
Area: Engineering.

EN.530.343. Design and Analysis of Dynamical Systems. 3.0 Credits.
Modeling and analysis of damped and undamped, forced and free vibrations in single and multiple degree-of-freedom linear dynamical systems. Introduction to stability and control of linear dynamical systems.
Prerequisites: Prereq: (110.108 and 110.109 and (110.202 or 110.211) and ((550.291) or (110.201 and 110.302) or (110.201 and 110.306)) and C- or better or concurrent enrollment in 530.202 or 560.202. MechE Majors must also have taken 530.241;Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): L. Whitcomb; S. Marra
Area: Engineering.
EN.530.414. Computer-Aided Design. 3.0 Credits.
The course outlines a modern design platform for 3D modeling, analysis, simulation, and manufacturing of mechanical systems using the "Pro/E" package by PTC. The package includes the following components: • Pro/ENGINEER: is the kernel of the design process, spanning the entire product development, from creative concept through detailed product definition to serviceability. • Pro/Mechanica: is the main analysis and simulation component for kinematic, dynamic, structural, thermal and durability performance. • Pro/NC: is a numeric-control manufacturing package. This component provides NC programming capabilities and tool libraries. It creates programs for a large variety of CNC machine tools. Instructor(s): D. Stoianovici
Area: Engineering.

EN.530.420. Robot Sensors/Actuators. 4.0 Credits.
Introduction to modeling and use of actuators and sensors in mechatronic design. Topics include electric motors, solenoids, micro-actuators, position sensors, and proximity sensors. Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.; ((AS.171.101 AND AS.171.102) OR (AS.171.107 AND AS.171.108) OR (EN.530.103 AND EN.530.104) OR (EN.530.123 AND EN.530.124)) AND (AS.110.106 OR AS.110.108) AND AS.110.109 AND (AS.110.202 OR AS.110.211) AND (EN.550.291 OR AS.110.302) AND (EN.530.241 OR EN.520.230 OR (EN.520.132 AND EN.520.345))
Instructor(s): D. Kraemer; N. Cowan
Area: Engineering.

EN.530.421. Mechatronics. 3.0 Credits.
Students from various engineering disciplines are divided into groups of two to three students. These groups each develop a microprocessor-controlled electromechanical device, such as a mobile robot. The devices compete against each other in a final design competition. Topics for competition vary from year to year. Class instruction includes fundamentals of mechanism kinematics, creativity in the design process, an overview of motors and sensors, and interfacing and programming microprocessors. Prerequisites: EN.530.420 or EN.520.240 or permission of instructor; Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): C. Rizk
Area: Engineering.

EN.530.424. Dynamics of Robots and Spacecraft. 3.0 Credits.
An introduction to Lagrangian mechanics with application to robot and spacecraft dynamics and control. Topics include rigid body kinematics, efficient formulation of equations of motion, stability theory, and Hamilton’s principle.
Instructor(s): G. Chirikjian; J. Kim
Area: Engineering.

EN.530.420. Robot Sensors/Actuators. 4.0 Credits.
Introduction to modeling and use of actuators and sensors in mechatronic design. Topics include electric motors, solenoids, micro-actuators, position sensors, and proximity sensors. Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.; ((AS.171.101 AND AS.171.102) OR (AS.171.107 AND AS.171.108) OR (EN.530.103 AND EN.530.104) OR (EN.530.123 AND EN.530.124)) AND (AS.110.106 OR AS.110.108) AND AS.110.109 AND (AS.110.202 OR AS.110.211) AND (EN.550.291 OR AS.110.302) AND (EN.530.241 OR EN.520.230 OR (EN.520.132 AND EN.520.345))
Instructor(s): D. Kraemer; N. Cowan
Area: Engineering.

EN.530.495. Microfabrication Laboratory. 4.0 Credits.
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprised of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photoresist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Seniors only or Permission Required.
Instructor(s): J. Wang
Area: Engineering, Natural Sciences.

EN.530.646. Robot Devices, Kinematics, Dynamics, and Control. 4.0 Credits.
Graduate-level introduction to the mechanics of robotic systems with emphasis on the mathematical tools for kinematics and dynamics of robot arms and mobile robots. Topics include the geometry and mathematical representation of rigid body motion, forward and inverse kinematics of articulated mechanical arms, trajectory generation, manipulator dynamics, actuation, and design issues, manipulator control, and additional special topics. Recommended course background: multivariable integral and differential calculus, classical physics, linear algebra, ordinary differential equations. Programming: Knowledge of the Matlab programming language including data input/output, 1-D and 2-D arrays, and user-defined function calls. Students with experience with these language elements in other programming languages (C, C++, Python, Java, etc.) should be able to self-tutor themselves in the Matlab language as part of the programming exercises.
Instructor(s): J. Kim

EN.530.653. Advanced Systems Modeling. 3.0 Credits.
This course covers the following topics at an advanced level: Newton’s laws and kinematics of systems of particles and rigid bodies; Lagrange’s equations for single- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion: structure, passivity, PD control, noise models and stochastic equations of motion; manipulator dynamics: Newton-Euler formulation, Langrange, Kane’s formulation of dynamics, computing torques with O(n) recursive manipulator dynamics: Lu-Walker-Paul, Hollerbach, O(n) dynamic simulation: Rodrigues-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which related the topics of this course to his or her research.
Instructor(s): G. Chirikjian.
EN.530.661. Applied Mathematics for Engineering. 3.0 Credits.
This course presents a broad survey of the basic mathematical methods used in the solution of ordinary and partial differential equations: linear algebra, vector calculus, power series, Fourier series, separation of variables, integral transforms.
Instructor(s): M. Hilpert.

EN.530.676. Locomotion II: Dynamics. 3.0 Credits.
Graduate course on mechanics and control in locomotion. Topics include modeling (e.g. Lagrangian mechanics), dynamical systems theory (nonholonomic systems, limit-cycle behavior, Poincaré analysis, and Floquet theory), design (control synthesis, mechanical design), and data-driven modeling from animal locomotor control experiments.
Prerequisites: A graduate course in linear systems theory (e.g. EN.520.601). Suggested background (not required): 530.475/675.
Instructor(s): N. Cowan.

EN.580.471. Principles of Design of BME Instrumentation. 4.0 Credits.
This core design course will cover lectures and hands-on labs. The material covered will include fundamentals of biomedical sensors and instrumentation, FDA regulations, designing with electronics, biopotentials and ECG amplifier design, recording from heart, muscle, brain, etc., diagnostic and therapeutic devices (including pacemakers and defibrillators), applications in prosthetics and rehabilitation, and safety. The course includes extensive laboratory work involving circuits, electronics, sensor design and interface, and building complete biomedical instrumentation. The students will also carry out design challenge projects, individually or in teams (examples include “smart cane for blind,” “computer interface for quadriplegic”). Students satisfying the design requirement must also register for EN.580.571. Lab Fee: $150. Recommended Course Background: EN.520.345
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): N. Thakor
Area: Engineering, Natural Sciences.

EN.553.291. Linear Algebra and Differential Equations. 4.0 Credits.
An introduction to the basic concepts of linear algebra, matrix theory, and differential equations that are used widely in modern engineering and science. Intended for engineering and science majors whose program does not permit taking both AS.110.201 and AS.110.302.
Prerequisites: AS.110.107 OR AS.110.109 OR AS.110.113
Instructor(s): M. Michel
Area: Engineering, Quantitative and Mathematical Sciences.

EN.553.457. Topics in Operations Research. 1.5 Credits.
Study in depth of a special mathematical or computational area of operations research, or a particular application area. Recent topics: decision theory, mathematical finance, optimization software.
Instructor(s): B. Castello
Area: Engineering, Quantitative and Mathematical Sciences.

EN.553.493. Mathematical Image Analysis. 3.0 Credits.
This course gives an overview of various mathematical methods related to several problems encountered in image processing and analysis, and presents numerical schemes to address them. It will focus on problems like image denoising and deblurring, contrast enhancement, segmentation and registration. The different mathematical concepts shall be introduced during the course; they include in particular functional spaces such as Sobolev and BV, Fourier and wavelet transforms, as well as some notions from convex optimization and numerical analysis. Most of such methods will be illustrated with algorithms and simulations on discrete images, using MATLAB. Prerequisites: linear algebra, multivariate calculus, basic programming in MATLAB. Recommended Course Background: Real analysis
Prerequisites: ( AS.110.202 OR AS.110.211 ) AND ( EN.550.291 OR AS.110.201 OR AS.110.212 ); Students may receive credit for EN.550.493/EN.553.493 or EN.553.693, but not both.
Instructor(s): P. Escande
Area: Engineering, Quantitative and Mathematical Sciences.

EN.553.762. Nonlinear Optimization II. 3.0 Credits.
This course considers algorithms for solving various nonlinear optimization problems and, in parallel, develops the supporting theory. The primary focus will be on constrained optimization problems. Topics for the course will include: necessary and sufficient optimality conditions for constrained optimization; projected-gradient and two-phase accelerated subspace methods for bound-constrained optimization; simplex and interior-point methods for linear programming; duality theory; and penalty, augmented Lagrangian, sequential quadratic programming, and interior-point methods for general nonlinear programming. In addition, we will consider the Alternating Direction Method of Multipliers (ADMM), which is applicable to a huge range of problems including sparse inverse covariance estimation, consensus, and compressed sensing. Recommended Course Background: Multivariable Calculus, Linear Algebra, Real Analysis such as AS.110.405.
Instructor(s): D. Robinson.

EN.580.472. Medical Imaging Systems. 3.0 Credits.
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Cross-listed with Neuroscience and Electrical and Computer Engineering (EN.520.432).
Prerequisites: EN.580.222 OR EN.520.214
Instructor(s): M. Bell
Area: Engineering.

EN.601.464. Artificial Intelligence. 3.0 Credits.
The class is recommended for all scientists and engineers with a genuine curiosity about the fundamental obstacles to getting machines to perform tasks such as learning, planning and prediction. Materials will be primarily based on the popular textbook, Artificial Intelligence: A Modern Approach. Strong programming skills are expected, as well as basic familiarity with probability. For students intending to also take courses in Machine Learning (e.g., 601.475/675, 601.476/676), they may find it beneficial to take this course first, or concurrently. [Applications]
Prerequisites: EN.600.226; Students may receive credit for only one of EN.600.335, EN.600.435, EN.601.464, EN.601.664.
Instructor(s): B. Van Durme
Area: Engineering.
EN.601.220. Intermediate Programming. 4.0 Credits.
This course teaches intermediate to advanced programming, using C and C++. (Prior knowledge of these languages is not expected.) We will cover low-level programming techniques, as well as object-oriented class design, and the use of class libraries. Specific topics include pointers, dynamic memory allocation, polymorphism, overloading, inheritance, templates, collections, exceptions, and others as time permits. Students are expected to learn syntax and some language specific features independently. Course work involves significant programming projects in both languages.
Prerequisites: AP Computer Science, or C+ or better in EN.600.107/EN.601.107 OR EN.580.200 OR EN.600.112.
Instructor(s): J. Selinski; M. Darvish Darab; S. More Area: Engineering.

EN.601.226. Data Structures. 4.0 Credits.
This course covers the design and implementation of data structures including arrays, stacks, queues, linked lists, binary trees, heaps, balanced trees (e.g. 2-3 trees, AVL-trees) and graphs. Other topics include sorting, hashing, memory allocation, and garbage collection. Course work involves both written homework and Java programming assignments.
Prerequisites: EN.600.120 OR EN.601.220 OR EN.600.107 OR EN.601.107 or equivalent with C+ or better grades.
Instructor(s): M. Schatz
Area: Engineering, Quantitative and Mathematical Sciences.

EN.601.455. Computer Integrated Surgery I. 4.0 Credits.
This course focuses on computer-based techniques, systems, and applications exploiting quantitative information from medical images and sensors to assist clinicians in all phases of treatment from diagnosis to preoperative planning, execution, and follow-up. It emphasizes the relationship between problem definition, computer-based technology, and clinical application and includes a number of guest lectures given by surgeons and other experts on requirements and opportunities in particular clinical areas. Recommended Course Background: EN.601.220, EN.601.457, EN.601.461, image processing.
Prerequisites: EN.600.226 AND ( AS.110.201 OR AS.110.212 ) or permission of the instructor.;Students may receive credit for only one of EN.600.445, EN.600.645, EN.601.455, EN.601.655.
Instructor(s): R. Taylor
Area: Engineering.

EN.601.456. Computer Integrated Surgery II. 3.0 Credits.
This weekly lecture/seminar course addresses similar material to EN.601.445, but covers selected topics in greater depth. In addition to material covered in lectures/seminars by the instructor and other faculty, students are expected to read and provide critical analysis/presentations of selected papers in recitation sessions. Students taking this course are required to undertake and report on a significant term project under the supervision of the instructor and clinical end users. Typically, this project is an extension of the term project from EN.601.445, although it does not have to be. Grades are based both on the project and on classroom recitations. Students wishing to attend the weekly lectures as a 1-credit seminar should sign up for EN.600.452. [Applications]
Prerequisites: EN.600.445 or EN.600.645 or permission;Students may receive credit for only one of EN.600.446, EN.600.646, EN.601.456, EN.601.656.
Instructor(s): R. Taylor
Area: Engineering.

EN.601.461. Computer Vision. 3.0 Credits.
This course gives an overview of fundamental methods in computer vision from a computational perspective. Methods studied include: camera systems and their modeling, computation of 3-D geometry from binocular stereo, motion, and photometric stereo; and object recognition. Edge detection and color perception are covered as well. Elements of machine vision and biological vision are also included. [Applications]
Prerequisites: intro programming, linear algebra, and prob/stat.
Prerequisites: Students may receive credit for only one of EN.600.361, EN.600.461, EN.600.661, EN.601.461, EN.601.661.
Instructor(s): H. Ali
Area: Engineering, Quantitative and Mathematical Sciences.

EN.601.475. Machine Learning. 3.0 Credits.
Machine learning is subfield of computer science and artificial intelligence, whose goal is to develop computational systems, methods, and algorithms that can learn from data to improve their performance. This course introduces the foundational concepts of modern Machine Learning, including core principles, popular algorithms and modeling platforms. This will include both supervised learning, which includes popular algorithms like SVMs, logistic regression, boosting and deep learning, as well as unsupervised learning frameworks, which include Expectation Maximization and graphical models. Homework assignments include a heavy programming components, requiring students to implement several machine learning algorithms in a common learning framework. Additionally, analytical homework questions will explore various machine learning concepts, building on the pre-requisites that include probability, linear algebra, multi-variate calculus and basic optimization. Students in the course will develop a learning system for a final project. [Applications or Analysis] Required course background: multivariable calculus, probability, linear algebra.
Prerequisites: EN.600.107 OR EN.600.120 OR EN.601.220 OR EN.600.226/EN.601.226 OR EN.580.200 OR EN.500.200 OR AS.250.205 OR EN.601.107 OR EN.500.112 OR AP Computer Science;Students may receive credit for only one of EN.600.475, EN.601.475, EN.601.675.
Instructor(s): M. Dredze
Area: Engineering.

EN.601.763. Algorithms for Sensor-Based Robotics. 3.0 Credits.
Similar material as EN.601.463 and EN.601.663, covered in more depth. [Applications] Recommended course background: EN.601.226, AS.110.106, probability and statistics.
Prerequisites: Students may only earn credit for one of the following: EN.600.336, EN.600.436/EN.601.463, EN.600.663, or EN.600.636/EN.601.763.
Instructor(s): S. Leonard.
EN.601.656. Computer Integrated Surgery II. 3.0 Credits.
Same material as EN.601.456, for graduate students. This weekly lecture/seminar course addresses similar material to EN.601.445, but covers selected topics in greater depth. In addition to material covered in lectures/seminars by the instructor and other faculty, students are expected to read and prepare critical analysis/presentations of selected papers in recitation sessions. Students taking this course are required to undertake and report on a significant term project under the supervision of the instructor and clinical end users. Typically, this project is an extension of the term project from EN.601.445, although it does not have to be. Grades are based both on the project and on classroom recitations. Students wishing to attend the weekly lectures as a 1-credit seminar should sign up for EN.601.452. [Applications] Prerequisites: EN.600.445 OR EN.600.645 OR PERMISSION OF INSTRUCTOR; Students may receive credit for only one of EN.600.446, EN.600.646, EN.601.456, EN.601.656.
Instructor(s): R. Taylor.

EN.601.760. FFT in Graphics & Vision. 3.0 Credits.
In this course, we will study the Fourier Transform from the perspective of representation theory. We will begin by considering the standard transform defined by the commutative group of rotations in 2D and translations in two- and three-dimensions, and will proceed to the Fourier Transform of the non-commutative group of 3D rotations. Subjects covered will include correlation of images, shape matching, computation of invariances, and symmetry detection. Recommended Course Background: AS.110.201 and comfort with mathematical derivations.
Instructor(s): M. Kazhdan.

EN.601.661. Computer Vision. 3.0 Credits.
Same material as 601.461, for graduate students. Students may receive credit for at most one of 601.461/661/761. This course gives an overview of fundamental methods in computer vision from a computational perspective. Methods studied include: camera systems and their modeling, computation of 3-D geometry from binocular stereo, motion, and photometric stereo; and object recognition. Edge detection and color perception are covered as well. Elements of machine vision and biological vision are also included. [Applications] Recommended Course Background: intro programming, linear algebra, prob/stat.
Prerequisites: Students may receive credit for only one of EN.600.361, EN.600.461, EN.600.661, EN.601.461, EN.601.661.
Instructor(s): H. Ali
Area: Engineering.

EN.601.463. Algorithms for Sensor-Based Robotics. 3.0 Credits.
This course surveys the development of robotic systems for navigating in an environment from an algorithmic perspective. It will cover basic kinematics, configuration space concepts, motion planning, and localization and mapping. It will describe these concepts in the context of the ROS software system, and will present examples relevant to mobile platforms, manipulation, robotics surgery, and human-machine systems. [Analysis] Prerequisites: EN.600.226 OR EN.601.226 and Linear Algebra and Probability; Students may receive credit for only one of EN.600.336, EN.600.436, EN.600.636, EN.601.463, EN.601.663.
Instructor(s): S. Leonard
Area: Engineering.

For current faculty and contact information go to https://www.lcsr.jhu.edu/Faculty

Faculty
Professors
Gregory Chirikjian

Noah Cowan
Professor (Mechanical Engineering): Robotics, Neuroscience, Dynamics, Controls, & Locomotion. Courses: System Identification; Robot Devices, Kinematics, Dynamics, and Control; Physics and Feedback in Living Systems; Locomotion in Mechanical and Biological Systems; Linear Systems.

Ralph Etienne-Cummings
Professor (Electrical and Computer Engineering): Neuromorphic Computational Sensing and Integrated Microsystems; Courses: CAD Design of Digital VLSI Systems, Electronics Design Laboratory, Seminar on Large Scale Analog Computation.

Gregory Hager

Jerry Prince
Professor (Biomedical Engineering): Biomedical Imaging, Computer Vision, Sensor-Based Robotics.

Russell Taylor
Professor (Computer Science): Medical Robotics and Computer-Integrated Interventional Systems, Medical Imaging and Modeling; Courses: Computer Integrated Surgery I & II.

Rene Vidal
Professor (Biomedical Engineering): Biomedical Imaging, Computer Vision and Machine Intelligence; Courses: Advanced Topics in Computer Vision, Advanced Topics in Machine Learning.

Louis Whitcomb

Associate Professor
Dennice Gayme

Assistant Professors
Jeremy Brown
Assistant Professor (Mechanical Engineering): Haptic feedback, upper-limb prosthetics, surgical robotics, rehabilitation robotics, human-machine interaction; Courses: Haptic Interface Design for Human-Robot Interaction.

Muyinatu (Bisi) Bell
Assistant Professor (Electrical and Computer Engineering): Medical Imaging, Medical Robotics, Image-Guided Surgery; Courses: Introduction to Medical Imaging, Ultrasound and Photoacoustic Beamforming.

Emad Boctor
Assistant Professor (Radiology): Image-Guided Intervention Ultrasound Imaging.

Chien-Ming Huang

Marin Kobilarov
Assistant Professor (Mechanical Engineering): Computational Dynamical Systems, Robot Control and Motion Planning; Courses: Applied Optimal Control, Nonlinear Control and Planning in Robotics.

Chen Li
Assistant Professor (Mechanical Engineering): Terradynamics, Locomotion, Comparative Biomechanics, Bio-Robotics, Robophysics; Courses: Locomotion I: Mechanics, Comparative BioMechanics.

Enrique Mallada
Assistant Professor (Electrical and Computer Engineering): Networked Dynamical Systems, Power Systems, Control Theory, Optimization; Courses: Networked Dynamical Systems.

Research Professor
Peter Kazanzides
Research Professor (Computer Science): Medical Robotics; Space Robots; Software Systems and Architectures; Robot Control Systems, Augmented Reality.

Nassir Navab

Associate Research Professor
Mehran Armand
Associate Research Professor (Mechanical Engineering) and Principal Staff (JHUAPL): Medical Robotics and Computer-Integrated Interventional Systems, Biomechanics; Courses: Kinematics and Dynamics of Robots, Robot Control.

Iulian Iordachita
Associate Research Professor (Mechanical Engineering): Medical Robotics; Mechanical Design, Medical Instrumentation, Sensorized Surgical Tools.

Assistant Research Professor
Simon Leonard