DEPARTMENT OF ELECTRICAL, COMPUTER, AND SYSTEMS ENGINEERING

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Pedram Mohseni, Professor and Chair of Electrical, Computer, and Systems Engineering (ECSE)
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Effective as of June 1, 2019, the Electrical Engineering and Computer Science Department in the Case School of Engineering has been renamed to be the Department of Electrical, Computer, and Systems Engineering (ECSE).

The ECSE Department spans a spectrum of topics from (i) materials, devices, circuits, and processors through (ii) control, signal processing, and systems analysis to (iii) human-machine interfaces, computation, computer systems, embedded systems and networking. The ECSE Department at Case Western Reserve supports three synergistic degree programs: Electrical Engineering, Computer Engineering, and Systems & Control Engineering. Each degree program leads to the Bachelor of Science degree at the undergraduate level. At the graduate level, the department offers the Master of Science and Doctor of Philosophy degrees in Electrical Engineering, Computer Engineering, and Systems & Control Engineering. We offer minors in Electrical Engineering, Computer Engineering, Systems & Control Engineering, and also in Computer Gaming, and Electronics. For supplemental information to this bulletin as well as the latest updates, please visit the ECSE Department website at https://engineering.case.edu/electrical-computer-and-systems-engineering (https://engineering.case.edu/electrical-computer-and-systems-engineering/).

ECSE is at the heart of modern technology. ECSE disciplines are responsible for the devices and microprocessors powering our computers and embedded into everyday devices, from cell phones and tablets to automobiles and airplanes. Healthcare is increasingly building on ECSE technologies: micro/nano-systems, electronics/instrumentation, implantable systems, embedded microprocessors, wireless medical devices, surgical robots, imaging, system biology, and visualization. The future of energy will be profoundly impacted by ECSE technologies, from smart appliances connected to the Internet, smart buildings that incorporate distributed sensing and control, to the envisioned smart grid that must be controlled, stabilized, and kept secure over an immense network. ECSE drives job creation and starting salaries in our fields are consistently ranked at the top of all college majors. Our graduates work in cutting-edge companies—from giants to start-ups, in a variety of technology sectors, including computer and internet, healthcare and medical devices, manufacturing and automation, automotive and aerospace, defense, finance, energy, and consulting.

Educational Philosophy
The ECSE department is dedicated to developing high-quality graduates who will take positions of leadership as their careers advance. We recognize that the increasing role of technology in virtually every facet of our society, life, and culture makes it vital that our students have access to progressive and cutting-edge higher education programs. The core values for all of the degree programs in the department are:

• mastery of fundamentals
• creativity
• social awareness
• leadership skills
• professionalism

Stressing excellence in these core values helps to ensure that our graduates are valued and contributing members of our global society and that they will carry on the tradition of engineering leadership established by our alumni.

Our goal is to graduate students who have fundamental technical knowledge of their profession and the requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance their fields. To achieve this goal, the department offers a wide range of technical specialties consistent with the breadth of electrical engineering, computer engineering, and systems & control engineering, including recent developments in the fields. Because of the rapid pace of advancement in these fields, our degree programs emphasize a broad and foundational science and technology background that equips students for future developments. Our programs include a wide range of electives and our students are encouraged to develop individualized programs which can combine many aspects of electrical engineering, computer engineering, and systems & control engineering.

Research
The research thrusts of the Electrical, Computer, and Systems Engineering department include:

1. Micro/Nano Systems
2. Electronics and Instrumentation
3. Robotics and Human-Machine Interfaces
4. Embedded Systems, including VLSI and FPGA design
6. Systems Biology
7. Machine Learning and Data Mining
8. Computer Networks and Distributed Systems
9. Energy Systems, including Wind and Power Grid Management/Control
10. Gaming, Simulation, Optimization
11. Medical Informatics and Wireless Health

ECSE participates in a number of groundbreaking collaborative research and educational programs, including the Microelectromechanical Systems Research Program, the Center for Computational Genomics, graduate program in Systems Biology and Bioinformatics, the Clinical & Translational Science Collaborative, the Great Lakes Energy Institute, and the VA Center for Advanced Platform Technology.

Faculty
Marc Buchner, PhD
(Michigan State University)
Associate Professor
Computer gaming and simulation, virtual reality, software-defined radio, wavelets, joint time-frequency analysis
M. Cenk Cavusoglu, PhD
(University of California, Berkeley)
Nord Professor of Engineering
Robotics, systems and control theory, and human-machine interfaces; with emphasis on medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

Vira Chankong, PhD
(Case Western Reserve University)
Associate Professor
Large-scale optimization; logic-based optimization; multi-objective optimization; optimization applications in radiation therapy treatment planning, medical imaging, manufacturing and production systems, and engineering design problems

Michael Fu, PhD
(Case Western Reserve University)
Timothy E. and Allison L. Schroeder Assistant Professor
Neuro-rehabilitation and motor-relearning, with emphasis on virtual environments, neuromuscular electrical stimulation, and haptic interfaces

Mario Garcia-Sanz, DrEng
(University of Navarra, Spain)
Professor
Robust and nonlinear control, quantitative feedback theory, multivariable control, dynamic systems, systems modeling and identification; energy innovation, wind energy, spacecraft, electrical, mechanical, environmental and industrial applications

Evren Gurkan-Cavusoglu, PhD
(Middle East Technical University)
Associate Professor
Systems and control theory, systems biology, computational biology, biological system modeling, signal processing applied to biological systems, signal processing

Hossein Miri Lavasani, PhD
(The Georgia Institute of Technology)
Assistant Professor
High performance integrated circuits and systems, Low power interface circuits for MEMS and sensors

Gregory S. Lee, PhD
(University of Washington)
Assistant Professor
Haptic devices, including low-power design and effects on perception; applications to robotic surgery and telesurgery; secure teleoperation

Pan Li, PhD
(University of Florida)
Associate Professor
Networks, Cybersecurity, Big data, Cyber-physical systems, Bioinformatics

Wei Lin, PhD
(Washington University in St. Louis)
Professor
Nonlinear control, dynamic systems and homogeneous systems theory, H-infinity and robust control, adaptive control, system parameter estimation and fault detection, nonlinear control applications to under-actuated mechanical systems, biologically-inspired systems and systems biology

Kenneth A. Loparo, PhD
(Case Western Reserve University)
Arthur L. Parker Professor
Stability and control of nonlinear and stochastic systems; fault detection, diagnosis, and prognosis; recent applications work in advanced control and failure detection of rotating machines, signal processing for the monitoring and diagnostics of physiological systems, and modeling, analysis, and control of power and energy systems

Behnam Malakooti, PhD, PE
(Purdue University)
Professor
Risk analysis and prediction, design and multiple-objective optimization of manufacturing/production/operations systems, NASA intelligent internet protocol systems and networks, feed-forward artificial neural networks, intelligent decision making

Mehran Mehregany, PhD
(Massachusetts Institute of Technology)
Professor
Research and development at the intersections of micro/nano-electromechanical systems, semiconductor silicon carbide and integrated circuits

Pedram Mohseni, PhD
(University of Michigan)
Goodrich Professor of Engineering Innovation and Chair
Biomedical microsystems, bioelectronics, wireless neural interfaces, CMOS interface circuits for MEMS, low-power wireless sensing/actuating microsystems

Wyatt S. Newman, PhD, PE
(Massachusetts Institute of Technology)
Professor
Mechatronics, high-speed robot design, force- and vision-based machine control, artificial reflexes for autonomous machines, rapid prototyping, agile manufacturing, mobile robotic platforms

Christos Papachristou, PhD
(Johns Hopkins University)
Professor
VLSI design and CAD, computer architecture and parallel processing, design automation, embedded system design

Daniel Saab, PhD
(University of Illinois at Urbana-Champaign)
Associate Professor
Computer architecture, VLSI system design and test, CAD design automation

Sree N. Sreenath, PhD
(University of Maryland)
Professor
Systems biology complexity research (modeling, structural issues, and simulation); cell signaling, population behavior, and large-scale behavior; global issues and sustainable development

Christian A. Zorman, PhD
(Case Western Reserve University)
F. Alex Nason Professor
Materials and processing techniques for MEMS and NEMS, wide bandgap semiconductors, development of materials and fabrication techniques for polymer-based MEMS and bioMEMS
Secondary Faculty Appointments

Vipin Chaudhary, PhD  
(University of Texas at Austin)  
*Professor, Computer and Data Sciences*

Kathryn Daltorio, PhD  
(Case Western Reserve University)  
*Assistant Professor, Mechanical & Aerospace Engineering*

Dominique Durand, Ph.D.  
(University of Toronto)  
*Professor, Biomedical Engineering*

Mark Griswold, PhD  
(University of Würzburg, Germany)  
*Professor, Radiology*

Anant Madabhushi, Ph.D.  
(University of Pennsylvania)  
*Professor, Biomedical Engineering*

Roger D. Quinn, PhD  
(Virginia Polytechnic Institute and State University)  
*Professor, Mechanical and Aerospace Engineering*

Satya S. Sahoo, PhD  
(Wright State University)  
*Associate Professor, Dept of Population & Quantitative Health Sciences*

Peter Thomas, PhD  
(University of Chicago)  
*Associate Professor, Mathematics, Applied Mathematics, and Statistics*

Dustin Tyler, PhD  
(Case Western Reserve University)  
*Professor, Biomedical Engineering*

Satish Viswanath, PhD  
(Rutgers University)  
*Assistant Professor, Biomedical Engineering*

Xiong (Bill) Yu, PhD, PE  
(Purdue University)  
*Professor, Civil and Environmental Engineering*

Adjunct Faculty Appointments

Hanieh Agharazi, PhD  
(Case Western Reserve University)  
*Adjunct Assistant Professor*

Nicholas Barendt, MSEE  
(Case Western Reserve University)  
*Adjunct Sr. Instructor*

Michael S. Branicky, ScD, PE  
(Massachusetts Institute of Technology)  
*Adjunct Professor*

Philip Feng, Ph.D.  
(California Institute of Technology)  
*Adjunct Professor*

Roberto Galan, PhD  
(Humboldt Universität zu Berlin, Germany)  
*Adjunct Associate Professor*

Suparerk Janjarasjitt, PhD  
(Case Western Reserve University)  
*Adjunct Assistant Professor*

David Kazdan, Ph.D.  
(Case Western Reserve University)  
*Adjunct Assistant Professor*

Soumyajit Mandal, Ph.D.  
(Massachusetts Institute of Technology)  
*Adjunct Associate Professor*

Amirhossein Sajadi, PhD  
(Case Western Reserve University)  
*Adjunct Assistant Professor*

Gideon Samid, PhD  
(Israel Institute of Technology)  
*Adjunct Assistant Professor*

Maximilian Scardelletti, PhD  
(Case Western Reserve University)  
*Adjunct Assistant Professor*

Lawrence Sears  
(Case Western Reserve University)  
*Adjunct Instructor*

Nicole Seiberlich, PhD  
(Universitaet Wuerzburg, Wuerzburg)  
*Adjunct Associate Professor*

Amit Sinha, PhD  
(Case Western Reserve University)  
*Adjunct Assistant Professor*

Benjamin Vandendriessche, PhD  
(Ghent University)  
*Adjunct Assistant Professor*

Francis G. Wolff, Ph.D.  
(Case Western Reserve University)  
*Adjunct Associate Professor*

Research Faculty

Mahdi Bayat, PhD  
(University of Minnesota)  
*Research Assistant Professor*  
Signal processing, biomedical imaging, machine learning

Farhad Kaffashi, PhD  
(Case Western Reserve University)  
*Research Assistant Professor*  
Signal processing of physiological time series data, systems and control

Michael A. Suster, Ph.D.  
(Case Western Reserve University)  
*Research Assistant Professor*  
Point-of-care diagnostic platforms, sensors, circuits, and microsystems
Program Educational Objectives

to become leaders in creating the new techniques and technologies that are important to the profession and the requisite technical breadth and communications skills.

Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.

Students will use continuous learning opportunities to improve and enhance their professional skills.

Graduates will demonstrate leadership in their profession.

Student Outcomes

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function in multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: signals and systems, solid state, computer hardware, computer software, control, circuits, robotics, and biomedical applications. Each electrical engineering student must complete the following requirements:

Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 321</td>
<td>Semiconductor Electronic Devices</td>
<td>4</td>
</tr>
</tbody>
</table>

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: signals and systems, solid state, computer hardware, computer software, control, circuits, robotics, and biomedical applications. Each electrical engineering student must complete the following requirements:

Technical Elective Requirement

Each student must complete eighteen (18) credit hours of approved technical electives. Technical electives shall be chosen to fulfill the depth requirement (see next) and otherwise increase the student’s understanding of electrical engineering. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all ECSE courses at the 200 level and above and can include
courses from other programs. All non-ECSE technical electives must be approved by the student's academic advisor.

**Depth Requirement**

Each student must show a depth of competence in one technical area by taking at least three courses from one of the following areas. This depth requirement may be met using a combination of the above core courses and a selection of open and technical electives. Alternative depth areas may be considered by petition to the program faculty.

**Area I: Signals & Control**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 351</td>
<td>Communications and Signal Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 354</td>
<td>Digital Communications</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 490</td>
<td>Digital Image Processing</td>
<td>3</td>
</tr>
<tr>
<td>MATH 307</td>
<td>Linear Algebra</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area II: Computer Software**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDS 293</td>
<td>Software Craftsmanship</td>
<td>4</td>
</tr>
<tr>
<td>CSDS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 310</td>
<td>Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 391</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 393</td>
<td>Software Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 373</td>
<td>Modern Robot Programming</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 473</td>
<td>Modern Robot Programming</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area III: Solid State**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 321</td>
<td>Semiconductor Electronic Devices</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 322/415</td>
<td>Integrated Circuits and Electronic Devices</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 422</td>
<td>Solid State Electronics II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 221</td>
<td>Introduction to Modern Physics</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area IV: Circuits**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 310</td>
<td>Principles of Biomedical Instrumentation</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 326</td>
<td>Instrumentation Electronics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 344</td>
<td>Electronic Analysis and Design</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 371</td>
<td>Applied Circuit Design</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 426</td>
<td>MOS Integrated Circuit Design</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area V: Computer Hardware**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 301</td>
<td>Digital Logic Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>ECSE 314</td>
<td>Computer Architecture</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 315</td>
<td>Digital Systems Design</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 317</td>
<td>Computer Design - FPGAs</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 318</td>
<td>VLSI/CAD</td>
<td>4</td>
</tr>
</tbody>
</table>

**Area VI: Biomedical Applications**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I (and 2 of the following 4 courses)</td>
<td>3</td>
</tr>
<tr>
<td>EBME 310</td>
<td>Principles of Biomedical Instrumentation</td>
<td>3</td>
</tr>
<tr>
<td>EBME 320</td>
<td>Biomedical Imaging</td>
<td>3</td>
</tr>
<tr>
<td>EBME 327</td>
<td>Bioelectric Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EBME 401D</td>
<td>Biomedical Instrumentation and Signal Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area VII: Robotics**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 275</td>
<td>Fundamentals of Robotics</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 373</td>
<td>Modern Robot Programming</td>
<td>3</td>
</tr>
<tr>
<td>or ECSE 473</td>
<td>Mobile Robotics</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>or ECSE 476</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 484</td>
<td>Computational Intelligence I: Basic Principles</td>
<td>3</td>
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<tr>
<td>ECSE 489</td>
<td>Robotics I</td>
<td>3</td>
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**Statistics Requirement**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>* STAT 333</td>
<td>Uncertainty in Engineering and Science may be substituted with approval of advisor</td>
<td>3</td>
</tr>
</tbody>
</table>

**Design Requirement**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 398</td>
<td>Engineering Projects I</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 399</td>
<td>Engineering Projects II</td>
<td>3</td>
</tr>
</tbody>
</table>

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in one or more of a spectrum of specialties, such as, control, signal processing, electronics, integrated circuit design and fabrication, and robotics. With the approval of the advisor, a student may emphasize other specialties by selecting elective courses from other programs or departments.

Additionally, math and statistics classes are highly recommended as an integral part of the student's technical electives to prepare for work in industry and government and for graduate school. The following math/ statistics classes are recommended and would be accepted as approved technical electives:

- MATH 201 Introduction to Linear Algebra for Applications
- MATH 307 Linear Algebra
- MATH 330 Introduction to Scientific Computing
- MATH 380 Introduction to Probability

Other Math/Statistics may be used as technical electives with the approval of the student's academic advisor.

Many courses have integral or associated laboratories in which students gain "hands-on" experience with electrical engineering principles and instrumentation. Students have ready access to the teaching laboratory.
facilities and are encouraged to use them during non-scheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

**Suggested Program of Study: Major in Electrical Engineering**

The following is a suggested program of study. Current students should always consult their advisors and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

<table>
<thead>
<tr>
<th>First Year</th>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
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</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
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<td></td>
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</tr>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td>4</td>
<td></td>
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<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
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<tr>
<td>**</td>
<td>18</td>
<td>15</td>
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<table>
<thead>
<tr>
<th>Second Year</th>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 123)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Design and Computer Organization (ECSE 281)</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
<td>3</td>
<td></td>
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<tr>
<td>Electronic Circuits (ECSE 245)</td>
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<td>Electromagnetic Fields I (ECSE 309)</td>
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<td>**</td>
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<table>
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<tr>
<th>Third Year</th>
<th>Units</th>
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<tr>
<td>Breadth elective**</td>
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<td>Statics and Strength of Materials (ENGR 200)**</td>
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<td>Statistics for Signal Processing (STAT 332)**</td>
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<tr>
<td>Signals and Systems (ENGR 246)</td>
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<tr>
<td>Breadth elective**</td>
<td>3</td>
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<tr>
<td>Approved technical elective**</td>
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<tr>
<td>Professional Communication for Engineers (ENGL 398)**</td>
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<tr>
<td>Semiconductor Electronic Devices (ECSE 321)</td>
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**Fourth Year**

<table>
<thead>
<tr>
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<tr>
<td>Approved technical elective**</td>
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<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Engineering Projects I (ECSE 398)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
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<tr>
<td>Approved technical elective**</td>
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<td></td>
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<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
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</tr>
<tr>
<td>Engineering Projects II (ECSE 399)</td>
<td>3</td>
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</tr>
<tr>
<td>**</td>
<td>16</td>
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</tr>
</tbody>
</table>

**Total Units in Sequence:** 128

**Hours Required for Graduation: 128**

* University general education requirement

** Engineering general education requirement

b Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.

c Students may replace STAT 332 Statistics for Signal Processing with STAT 333 Uncertainty in Engineering and Science if approved by their advisor.

d Technical electives will be chosen to fulfill the depth requirement and otherwise increase the student's understanding of electrical engineering. Courses used to satisfy the depth requirement must come from the department's list of depth areas and related courses. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all ECSE courses at the 200 level and above, and can include courses from other programs. All non-ECSE technical electives must be approved by the student's advisor.

e BS/MS students may double count ECSE 651 Thesis M.S. to fulfill the ECSE 399 Engineering Projects II requirement.

f CO-OP students may obtain design credit for ECSE 399 Engineering Projects II if their co-op assignment included significant design responsibility; however, the student is still responsible for such course obligations as reports, presentations, and ethics assignments. Design credit and fulfillment of remaining course responsibilities are arranged through the course instructor.

Double Major: Systems and Control Engineering & Electrical Engineering
The department also offers a double major in Systems and Control Engineering and Electrical Engineering. Students pursuing the Bachelor of Science in Engineering degree program with a major in Electrical Engineering can take the following courses as technical and open electives to earn a second major in Systems and Control Engineering:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 216</td>
<td>Fundamental System Concepts</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 305</td>
<td>Control Engineering I Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>ECSE 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 342</td>
<td>Introduction to Global Issues</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 352</td>
<td>Engineering Economics and Decision Analysis</td>
<td>3</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications (SC)</td>
<td>3</td>
</tr>
<tr>
<td>OPRE 432</td>
<td>Computer Simulation (SC)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>And one of the following two courses:</td>
<td></td>
</tr>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
</tbody>
</table>

Cooperative Education Program in Electrical Engineering
Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at http://engineering.case.edu/coop/. Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program in Electrical Engineering
The department encourages highly motivated and qualified students to apply for admission to the BS/MS Program in the junior year. This integrated program permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute 3 credit hours of MS thesis work for ECSE 399 Engineering Projects II). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years. Review the Office of Undergraduate Studies BS/MS program requirements (http://bulletin.case.edu/undergraduatestudies/gradprofessional/accerlerationtowardgraduatedegreetext).

Minor in Electrical Engineering
Students enrolled in degree programs other than Electrical Engineering can have a minor specialization by completing the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approved technical elective</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td>Total Units</td>
<td></td>
<td><strong>18</strong></td>
</tr>
</tbody>
</table>

Minor in Electronics
The department also offers a minor in electronics for students in the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the students’ skills and distribution requirements. The following courses are required for the electronics minor:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 210</td>
<td>Introduction to Circuits and Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>MATH 125</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci</td>
<td>4</td>
</tr>
<tr>
<td>MATH 126</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci II</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 115</td>
<td>Introductory Physics I</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 116</td>
<td>Introductory Physics II</td>
<td>4</td>
</tr>
<tr>
<td>Total Units</td>
<td></td>
<td><strong>31</strong></td>
</tr>
</tbody>
</table>

Bachelor of Science in Systems and Control Engineering
The Bachelor of Science in Engineering degree program with a major in Systems and Control Engineering provides our students with the basic concepts, analytical tools, and engineering methods which are needed in analyzing and designing complex technological and non-technological systems. Problems relating to modeling, simulation, decision-making, control, and optimization are studied. Some examples of systems problems which are studied include: modeling and analysis of complex biological systems, computer control of industrial plants, developing world models for studying environmental policies, and optimal planning and management in large-scale systems. In each case, the relationship and interaction among the various components of a given system must be modeled. This information is used to determine the best way of coordinating and regulating these individual contributions to achieve the overall goal of the system.

The Bachelor of Science in Engineering with a major in Systems and Control Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/.

Mission
The mission of the Systems and Control Engineering program is to provide internationally recognized excellence for graduate and undergraduate education and research in systems analysis, design, and
control. These theoretical and applied areas require cross-disciplinary tools and methods for their solution.

Program Educational Objectives
1. Graduates apply systems methodology to multi-disciplinary projects that include technical, social, environmental, and/or economic factors.
2. Graduates use systems understanding, thinking and problem-solving skills to analyze and design systems or processes that respond to technical and societal needs.
3. Graduates use teamwork, leadership, communication, and management skills to facilitate multidisciplinary projects that bring together practitioners of various engineering fields in an effective, professional, and ethical manner.

Student Outcomes
- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function in multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively

Major in Systems and Control Engineering
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree/) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms/), the major requires the following courses:

Major Requirements
- ECSE 216 Fundamental System Concepts 3
- ECSE 246 Signals and Systems 4
- ECSE 304 Control Engineering I with Laboratory 3
- ECSE 305 Control Engineering I Laboratory 1
- ECSE 313 Signal Processing 3
- ECSE 324 Modeling and Simulation of Continuous Dynamical Systems 3
- ECSE 342 Introduction to Global Issues 3
- ECSE 346 Engineering Optimization 3
- ECSE 352 Engineering Economics and Decision Analysis 3
- ECSE 399 Engineering Projects II 3
- OPRE 432 Computer Simulation 3

Fifteen hours of approved technical electives including at least 9 hours of approved courses to constitute a depth of study

Breadth Requirement
- MATH 201 Introduction to Linear Algebra for Applications 3
- STAT 332 Statistics for Signal Processing 3

Statistics Requirement
- STAT 332 Statistics for Signal Processing 3

* STAT 333 Uncertainty in Engineering and Science may be substituted with approval of advisor

Design Requirement
- ECSE 398 Engineering Projects I 4

Depth Requirement
Each student must show a depth of competence in one technical area by taking at least three courses from one of the three tracks/program concentration areas, namely energy systems, control systems and data analytics, listed below:

Track 1: Energy Systems
- ECSE 368 Power System Analysis I 3
- ECSE 369 Power System Analysis II 3
- ECSE 370 Smart Grid 3
- ECSE 374 Advanced Control and Energy Systems 3
- ECSE 375 Applied Control 3
- ECSE 281 Logic Design and Computer Organization 4

Track 2: Control Systems
- ECSE 374 Advanced Control and Energy Systems 3
- ECSE 375 Applied Control 3
- ECSE 281 Logic Design and Computer Organization 4

Technical Elective from the Energy Systems or Data Analytics tracks

Track 3: Data Analytics
- CSDS 313 Introduction to Data Analysis
- “Core Tools” list:
  - CSDS 339 Web Data Mining 3
  - CSDS 435 Data Mining 3
  - ECSE 452 Random Signals 3
  - ECSE 490 Digital Image Processing 3
  - OPRE 433 Statistical Data Analytics for Supply Chain 3
  - STAT 325 Data Analysis and Linear Models 3
  - STAT 326 Multivariate Analysis and Data Mining 3
- “Application” lists:
  - Business/Manufacturing Analytics
    - BAFI 361 Empirical Analysis in Finance 3
    - ECSE 350 Operations and Systems Design 3
    - ECSE 360 Manufacturing and Automated Systems 3
    - ECSE 490 Digital Image Processing 3
    - MKMR 310 Marketing Analytics 3
    - OPMT 475 Global Supply Chain Logistics 3
### Healthcare Analytics

<table>
<thead>
<tr>
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<th>Title</th>
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<tr>
<td>BIOL 304</td>
<td>Fitting Models to Data: Maximum Likelihood Methods and Model Selection</td>
<td>3</td>
</tr>
<tr>
<td>EBME 410</td>
<td>Medical Imaging Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 319</td>
<td>Applied Probability and Stochastic Processes for Biology</td>
<td>3</td>
</tr>
<tr>
<td>MATH 378</td>
<td>Computational Neuroscience</td>
<td>3</td>
</tr>
<tr>
<td>SYBB 421</td>
<td>Fundamentals of Clinical Information Systems</td>
<td>3</td>
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</table>

### Energy Systems Analytics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>ECSE 370</td>
<td>Smart Grid</td>
<td>3</td>
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</table>

### Suggested Program of Study: Major in Systems and Control Engineering

The following is a suggested program of study. Current students should always consult their advisors and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu/).

#### First Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Fall</th>
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<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
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<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
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<td>Open elective</td>
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<td>PHED (2 half semester courses)*</td>
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<tr>
<td>SAGES University Seminar*</td>
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<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
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<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
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<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
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<td>PHED (2 half semester courses)*</td>
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#### Second Year

<table>
<thead>
<tr>
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<th>Spring</th>
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<tbody>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
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<td>Calculus for Science and Engineering III (MATH 223)**</td>
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<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
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<td></td>
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<tr>
<td>Statistics for Signal Processing (STAT 332)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
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<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
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<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
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<tr>
<td>Introduction to Linear Algebra for Applications (MATH 201)</td>
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<td></td>
</tr>
<tr>
<td>Fundamental System Concepts (ECSE 216)</td>
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<td><strong>16</strong></td>
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#### Third Year

<table>
<thead>
<tr>
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<th>Spring</th>
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<tbody>
<tr>
<td>Breadth elective**</td>
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<td></td>
</tr>
<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Signals and Systems (ECSE 246)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Modeling and Simulation of Continuous Dynamical Systems (ECSE 324)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Introduction to Global Issues (ECSE 342)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Computer Simulation (OPRE 432)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Control Engineering I with Laboratory (ECSE 304)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Control Engineering I Laboratory (ECSE 305)</td>
<td>1</td>
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</tr>
<tr>
<td>Engineering Optimization (ECSE 346)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Signal Processing (ECSE 313)</td>
<td>3</td>
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<tr>
<td><strong>Year Total:</strong></td>
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<td><strong>16</strong></td>
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#### Fourth Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398)**</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Engineering Economics and Decision Analysis (ECSE 352)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Engineering Projects I (ECSE 398)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Approved technical elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Engineering Projects II (ECSE 399)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>Year Total:</strong></td>
<td><strong>16</strong></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

#### Total Units in Sequence: 129

### Hours Required for Graduation: 129

---

* University general education requirement
** Engineering general education requirement
a Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.
b Co-op students may obtain design credit for one semester of Senior Project Lab if their co-op assignment includes significant design responsibility. This credit can be obtained by submitting a suitable written report and making an oral presentation on the co-op work in coordination with the senior project instructor.
Technical electives from approved list of courses in the three tracks/program concentration areas (Energy systems, Control systems, and Data Analytics) listed under "Depth Requirement" above.

There are five technical elective courses available within the Bachelor of Science in Engineering degree program with a major in Systems and Control Engineering curriculum that represent a depth of the discipline. Students can satisfy these five technical elective requirements by choosing three courses from one of the three tracks (to meet the Depth Requirement) with the fourth and fifth courses chosen from any of the three tracks listed under the Depth Requirement section above.

Double Major: Systems and Control Engineering & Electrical Engineering

From Systems and Control Engineering (S&CE) to Electrical Engineering (EE): S&CE students can earn a double major with EE by taking the following four courses as Technical Electives in the S&CE program:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 321</td>
<td>Semiconductor Electronic Devices</td>
<td>4</td>
</tr>
</tbody>
</table>

And one of the following two courses:

As the three courses ECSE 281, ECSE 245, and ECSE 321 are 4 credit-hours instead of 3, the three credit-hour "Open Elective" course in the original S&CE program is not needed.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
</tbody>
</table>

Cooperative Education Program in Systems and Control Engineering

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at http://engineering.case.edu/coop/. Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program in Systems and Control Engineering

The department encourages highly motivated and qualified students to apply for admission to the BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for ECSE 399 Engineering Projects II, the second senior project). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years. Review the Office of Undergraduate Studies BS/MS program requirements (http://bulletin.case.edu/undergraduatestudies/gradprofessional/accelerationtowardgraduatedegree/text).

Minor in Systems and Control Engineering

A total of five courses (15 credit hours) are required to obtain a minor in systems and control engineering. This includes:

- ECSE 246 Signals and Systems
- Three of the following four courses selected in consultation with the program minor advisor: ECSE 304 Control Engineering I with Laboratory/ECSE 305 Control Engineering I Laboratory; ECSE 324 Modeling and Simulation of Continuous Dynamical Systems; ECSE 346 Engineering Optimization; ECSE 352 Engineering Economics and Decision Analysis;
- One of ECSE 313 Signal Processing, ECSE 351 Communications and Signal Analysis, or ECSE 354 Digital Communications.

Bachelor of Science in Computer Engineering

The Bachelor of Science in Engineering degree program with a major in Computer Engineering is designed to give a student a strong background in the fundamentals of computer engineering through combined classroom and laboratory work. A graduate of this program will be able to use these fundamentals to analyze and evaluate computer systems, both hardware and software. A computer engineering graduate would also be able to design and implement a computer system for general purpose or embedded computing incorporating state-of-the-art solutions to a variety of computing problems. This includes systems which have both hardware and software components, whose design requires a well-defined interface between the two and the evaluation of the associated trade-offs.

The Bachelor of Science in Engineering degree program with a major in Computer Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/.

Mission

The educational mission of the computer engineering program is to graduate students who have fundamental technical knowledge of their profession along with requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance the general field of computer engineering. Core courses provide our students with a strong background in digital systems design, computer organization, hardware architecture, and digital electronics.

Program Educational Objectives

1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.
2. Graduates will engage in life-long learning to improve and enhance their professional skills.
3. Graduates will demonstrate leadership in their profession by using their knowledge, communication skills, and engineering ability.

Student Outcomes

As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Computer Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
• an ability to function in multi-disciplinary teams
• an ability to identify, formulate, and solve engineering problems
• an understanding of professional and ethical responsibility
• an ability to communicate effectively

Major in Computer Engineering
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree/) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms/), the major requires the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 301</td>
<td>Digital Logic Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>ECSE 314</td>
<td>Computer Architecture</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 315</td>
<td>Digital Systems Design</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 210</td>
<td>Introduction to Circuits and Instrumentation</td>
<td>4</td>
</tr>
</tbody>
</table>

Statistics Requirement
One Statistics elective may be chosen from:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 312</td>
<td>Basic Statistics for Engineering and Science</td>
<td>3</td>
</tr>
<tr>
<td>STAT 313</td>
<td>Statistics for Experimenters</td>
<td>3</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>STAT 333</td>
<td>Uncertainty in Engineering and Science</td>
<td>3</td>
</tr>
</tbody>
</table>

Design Requirement
ECSE 398: Engineering Projects I

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 398</td>
<td>Engineering Projects I</td>
<td>4</td>
</tr>
</tbody>
</table>

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in the principles and practice of computer engineering. Students must take 5-6 courses, that add up to 18 credit hours of technical electives, to fulfill this requirement. With the approval of the advisor, a student may emphasize a specialty of his/her choice by selecting elective courses from other programs or departments.

Many courses have integral or associated laboratories in which students gain "hands-on" experience with computer engineering principles and instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during non-scheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

Suggested Program of Study: Major in Computer Engineering
The following is a suggested program of study. Current students should always consult their advisors and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu/).

### First Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Introduction to Programming in Java (ECSE 132)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>18 15</td>
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</table>

### Second Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES University Seminar*</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Introduction to Data Structures (ECSE 233)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical elective³</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Logic Design and Computer Organization (ECSE 281)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>18 16</td>
</tr>
</tbody>
</table>

### Third Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRE 351</td>
<td>Engineering Projects I</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Discrete Mathematics (CSDS 302)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical elective³</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Digital Logic Laboratory (ECSE 301)</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Computer Architecture (ECSE 314)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Digital Systems Design (ECSE 315)</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Embedded Systems Design and Laboratory (ECSE 303)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>17 15</td>
<td></td>
</tr>
</tbody>
</table>

### Fourth Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRE 351</td>
<td>Engineering Projects I</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Discrete Mathematics (CSDS 302)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical elective³</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Digital Logic Laboratory (ECSE 301)</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Computer Architecture (ECSE 314)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Digital Systems Design (ECSE 315)</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Embedded Systems Design and Laboratory (ECSE 303)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>17 15</td>
<td></td>
</tr>
</tbody>
</table>
The Department of Electrical, Computer, and Systems Engineering offers a minor in computer engineering. The minor has a required two-course sequence followed by a two-course sequence in either hardware or software aspects of computer engineering.

The following two courses are required for any minor in computer engineering:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
</tbody>
</table>

Students should note that ECSE 132 Introduction to Programming in Java is a prerequisite for ECSE 233 Introduction to Data Structures.

The two-course hardware sequence is:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 303</td>
<td>Embedded Systems Design and Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 303</td>
<td>Embedded Systems Design and Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

The corresponding two-course software sequence is:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 3XX</td>
<td>Approved by advisor</td>
<td>4</td>
</tr>
</tbody>
</table>

**Minor in Artificial Intelligence (AI)**

The Computer and Data Sciences Department offers a minor in Artificial Intelligence (AI). For more information on the requirements for the minor, visit the Computer and Data Sciences General Bulletin page (http://bulletin.case.edu/schoolofengineering/compdatasci/#undergraduatetext).

**Minor in Computer Gaming (CGM)**

The minor is 16 hours as follows:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDS 391</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>or CSDS 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 290</td>
<td>Introduction to Computer Game Design and Implementation</td>
<td>3</td>
</tr>
<tr>
<td>or CSDS 290</td>
<td>Introduction to Computer Game Design and Implementation</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 366</td>
<td>Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>or CSDS 366</td>
<td>Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 390</td>
<td>Advanced Game Development Project</td>
<td>3</td>
</tr>
<tr>
<td>or CSDS 390</td>
<td>Advanced Game Development Project</td>
<td>3</td>
</tr>
</tbody>
</table>

It is recommended that one additional open elective be a “content creation” course taken from the following areas: Art, English, or Music. Students should note that ECSE 132 Introduction to Programming in Java is a prerequisite for ECSE 233 Introduction to Data Structures.

**Graduate Programs**

**MS Degree Programs**

The Department of Electrical, Computer, and Systems Engineering offers the following Master of Science degrees:

- Electrical Engineering MS
- Computer Engineering MS
- Systems and Control Engineering MS
Admission
Graduate students shall be admitted to one of three MS degree tracks (thesis-focused, project-focused, course-focused) upon recommendation of the faculty of the Department. Requirements for admission include a strong record of scholarship in a completed bachelor’s degree program in a field of engineering, mathematical or physical sciences, and fluency in written and spoken English.

For a thesis-focused or project-focused track, the University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 90 on the internet-based exam. For a course-focused track, a minimum TOEFL score of 80 is required. If there is any professional student-to-student interaction, e.g. as a teaching assistant, a lab instructor, or a tutor, then a minimum TOEFL score of 90 is required.

It is required that all students submit original copies of GRE scores, with the exception of CWRU students applying to the BS/MS program. Applications from students with a bachelor’s degree in fields other than those listed above may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission.

Registration
Course registration is performed through the Student Information System (SIS). Each semester before registration, students should update any personal information that may have changed by logging into SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

Advising
Upon admission to the graduate program, each graduate student is assigned an academic advisor to assist in registration as well as planning a program of study (Academic Program). This is a temporary assignment made by the Department Chairperson based on the student’s academic and research interests as identified at the time of application.

During the first semester in the program, it is strongly suggested that each student meet with various members of faculty to discuss academic objectives/goals and research opportunities. In order to complete the research component of their respective degree program, each student must identify a faculty member who is willing to serve as the student’s research advisor. Students are expected to pick a research advisor by the end of their first semester in the program who will supervise their thesis or project. Each student, in consultation with their advisor, must submit an Academic Program preferably before completing 9 credit hours of coursework. This should specify all courses and thesis work that will be counted toward the 30 credit hour requirement.

The research advisor will also serve as the student’s permanent academic advisor if they are a member of the department faculty. If, however, the research advisor is not a member of the department faculty, the student is required to find a permanent academic advisor from the department faculty. For students enrolled in an MS Thesis-Focused degree program, the research advisor is commonly known as the “thesis advisor”.

Students may change advisors for a variety of reasons of which one of the most common is a change of the student’s field of interest. It should be noted that a change in research advisor may require that the student start a new research project, which could result in delaying graduation. It is the responsibility of the student to inform the ECSE Office of Student Affairs in the event of a change in advisor. In addition, the student must file all appropriate forms with Graduate Studies.

Appeals
Any decision by an academic advisor, thesis guidance committee or department associate chairperson may be appealed, in writing, to the department associate chairperson who shall present the appeal, with their recommendations, to the faculty at its next regular faculty meeting. The faculty’s decision shall be final.

Other Regulations
All students pursuing graduate studies in the Department of Electrical, Computer, and Systems Engineering must abide by the academic regulations of the School of Graduate Studies (http://bulletin.case.edu/schoolofgraduatestudies/academicrequirements/) and the Case School of Engineering contained in the most recent issue of the Bulletin of Case Western Reserve University, and supplemented by the Department of Electrical, Computer, and Systems Engineering regulations.

Electrical Engineering MS
Thesis-Focused Track
The MS Thesis-Focused track is composed of two components:

1. graduate-level coursework and
2. a research-oriented thesis

Progression through the program is monitored by an Academic Program that is required to be filed through SIS. This contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by the student’s academic advisor, Department Chairperson, and Dean of Graduate Studies.

At least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 18 credits must be from non-thesis related courses is required. Each Electrical Engineering MS Thesis-Focused student must complete at least 9 credit hours of ECSE 651 Thesis M.S., which is the course associated with MS thesis research. Each student must complete their approved Academic Program coursework with a cumulative grade point average of 3.0 or greater.

Completion of the MS Thesis-Focused track requires that the student submit a written thesis and make an oral presentation of the findings (hereafter known as the defense) to a thesis guidance committee. The thesis guidance committee shall consist of the student’s research advisor and at least two additional faculty members recommended by the advisor. At least two members of the committee must be faculty members in the ECSE department. The chairperson of the guidance committee is normally the candidate’s research advisor. The student is responsible for forming the thesis guidance committee. The student will work closely with their advisor to determine when the thesis is ready for review by the guidance committee. The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the ECSE Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

Project-Focused Track
The MS Project-Focused track is composed of two components:

1. graduate-level coursework and
2. a research-oriented project

Progression through the program is monitored by an Academic Program that is required to be filed through SIS. The Academic Program contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by the student’s academic advisor, Department Chairperson, and Dean of Graduate Studies.
The Academic Program must contain at least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 21 credits from courses other than ECSE 695 Project M.S. (which is the course associated with the MS research project) is required. Each Electrical Engineering MS Project-Focused student must complete at least 3 credit hours of ECSE 695 Project M.S.. Each student must complete their approved Academic Program coursework with a cumulative grade point average of 3.0 or greater.

Each candidate for the Electrical Engineering master’s degree under a Project-Focused track must pass a comprehensive examination to be administered by a committee of department faculty. The examination committee should be composed of the student’s academic advisor and at least two additional members of the department faculty. In such cases, the chairperson of the committee is normally the candidate’s academic advisor. The examination may be written, oral, or a combination as determined by the committee. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master’s Comprehensive Exam.

**Course-Focused Track**
The Course-Focused MS track requirements consist of:

1. the completion of 30 hours of approved coursework at the 400 level or higher,
2. satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student’s curricular program, and
3. additional requirements as specified by the program.

Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

**Computer Engineering MS**

**Thesis-Focused Track**
The MS Thesis-Focused track is composed of two components:

1. graduate-level coursework and
2. a research-oriented thesis

Progression through the program is monitored by an Academic Program that is required to be filed through SIS. This contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by the student’s academic advisor, Department Chairperson, and Dean of Graduate Studies.

At least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 18 credits must be from non-thesis related courses is required. Each Computer Engineering MS Thesis-Focused student must complete at least 9 credit hours of ECSE 651 Thesis M.S., which is the course associated with MS thesis research. Each student must complete their approved Academic Program coursework with a cumulative grade point average of 3.0 or greater.

Completion of the MS Thesis-Focused track requires that the student submit a written thesis and make an oral presentation of the findings (hereafter known as the defense) to a thesis guidance committee. The thesis guidance committee shall consist of the student’s research advisor and at least two additional faculty members recommended by the advisor. At least two members of the committee must be faculty members in the ECSE department. The chairperson of the guidance committee is normally the candidate’s research advisor. The student is responsible for forming the thesis guidance committee. The student will work closely with their advisor to determine when the thesis is ready for review by the guidance committee. The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the ECSE Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

**Project-Focused Track**
The MS Project-Focused track is composed of two components:

1. graduate-level coursework and
2. a research-oriented project

Progression through the program is monitored by an Academic Program that is required to be filed through SIS. The Academic Program contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by the student’s academic advisor, Department Chairperson, and Dean of Graduate Studies.

The Academic Program must contain at least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 21 credits from courses other than ECSE 695 Project M.S. (which is the course associated with the MS research project) is required. Each Computer Engineering MS Project-Focused student must complete at least 3 credit hours of ECSE 695 Project M.S.. Each student must complete their approved Academic Program coursework with a cumulative grade point average of 3.0 or greater.

Each candidate for the Computer Engineering master’s degree under a Project-Focused track must pass a comprehensive examination to be administered by a committee of department faculty. The examination committee should be composed of the student’s academic advisor and at least two additional members of the department faculty. In such cases, the chairperson of the committee is normally the candidate’s academic advisor. The examination may be written, oral, or a combination as determined by the committee. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master’s Comprehensive Exam.

**Course-Focused Track**
The Course-Focused MS track requirements consist of:

1. the completion of 30 hours of approved coursework at the 400 level or higher,
2. satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student’s curricular program, and
3. additional requirements as specified by the program.

Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

**Systems and Control Engineering MS**

**Thesis-Focused Track**
The MS Thesis-Focused track is composed of two components:

1. graduate-level coursework and
2. a research-oriented thesis

Progression through the program is monitored by an Academic Program that is required to be filed through SIS. This contains a comprehensive list of all courses to be applied to the degree (including transfer courses)
The Course-Focused MS track requirements consist of:

- Comprehensive Exam
  - will be required to register for one semester hour of examination if taken. If not registered for other courses, the student or a combination as determined by the committee. A student must be the candidate's academic advisor. The examination may be written, oral, or a combination as determined by the faculty. In such cases, the chairperson of the committee is normally the candidate's research advisor. The student is responsible for forming the thesis guidance committee. The student will work closely with their advisor to determine when the thesis is ready for review by the guidance committee. The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the ECSE Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

**Project-Focused Track**

The MS Project-Focused track is composed of two components:

1. graduate-level coursework and
2. a research-oriented project

Progression through the program is monitored by an Academic Program that is required to be filed through SIS. The Academic Program contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by the student’s academic advisor, Department Chairperson, and Dean of Graduate Studies.

The Academic Program must contain at least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 21 credits are required. Each student must complete their approved Academic Program coursework with a cumulative grade point average of 3.0 or greater.

Each candidate for the Systems and Control Engineering master's degree under a Project-Focused track must pass a comprehensive examination to be administered by a committee of department faculty. The examination committee should be composed of the student’s academic advisor and at least two additional members of the department faculty. In such cases, the chairperson of the committee is normally the candidate’s academic advisor. The examination may be written, oral, or a combination as determined by the committee. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master's Comprehensive Exam.

**Course-Focused Track**

The Course-Focused MS track requirements consist of:

1. the completion of 30 hours of approved coursework at the 400 level or higher,
2. satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student’s curricular program, and
3. additional requirements as specified by the program.

Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

**PhD Degree Programs**

The Department of Electrical, Computer, and Systems Engineering offers the following Doctor of Philosophy degrees:

- Electrical Engineering PhD
- Computer Engineering PhD
- Systems and Control Engineering PhD

**Admission**

Requirements for admission include a strong record of scholarship in a completed bachelor's degree program in a field of engineering, mathematical or physical sciences, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 577 on the paper-based exam or 90 on the internet-based exam. It is required that all students submit original copies of GRE scores. Applications from students with a bachelor’s degree in fields other than those listed above may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission.

**Registration**

Course registration is performed through the Student Information System (SIS). Each semester before registration, students should update any personal information that may have changed by logging into SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

**Advising**

Upon admission to the graduate program, each graduate student is assigned an academic advisor to assist in registration as well as planning a program of study (Academic Program). This is a temporary assignment made by the Department Chairperson based on the student’s academic and research interests as identified at the time of application.

During the first two semesters in the program, it is strongly suggested that each student meet with various members of faculty to discuss academic objectives/goals and research opportunities. In order to complete the research component of their respective degree program, each student must identify a faculty member who is willing to serve as the student’s research advisor. The research advisor will also serve as the student’s permanent academic advisor if they are a member of the department faculty. If, however, the research advisor is not a member of the department faculty, the student is required to find a permanent academic advisor from the department faculty. For students enrolled in the PhD program, the research advisor is commonly known as the “dissertation” advisor.

Each student is required to file an Academic Program, which must be approved by the student’s advisor and the Department Chairperson, and submitted to the Dean of Graduate Studies. Full-time PhD students
should choose a research advisor and file an Academic Program before taking the qualifier but no later than the beginning of the third semester. Upon passing the qualifier, full-time PhD students will be required to assemble the dissertation guidance committee, prepare a dissertation proposal, and present this proposal to the committee for their approval. This process should be completed within one semester of passing the PhD qualifier.

The student shall be responsible for forming a dissertation guidance committee which shall consist of the student's academic advisor and additional faculty members recommended by the advisor. For the PhD program, the minimum number of additional faculty members on the dissertation guidance committee is three, and at least two of the committee must be within the ECSE program areas (Computer Engineering, Electrical Engineering, and Systems and Control Engineering). The chairperson of the dissertation guidance committee is normally the candidate's research advisor.

Students may change advisors for a variety of reasons of which one of the most common is a change of the student's field of interest. It should be noted that a change in research advisor may require that the student start a new research project, which could result in delaying graduation. It is the responsibility of the student to inform the ECSE Office of Student Affairs in the event of a change in advisor.

Appeals
Any decision by an academic advisor, dissertation guidance committee or Department Associate Chairperson may be appealed, in writing, to the Department Associate Chairperson who shall present the appeal, with their recommendations, to the faculty at its next regular faculty meeting. The faculty's decision shall be final.

Other Regulations
All students pursuing graduate studies in the Electrical, Computer, and Systems Engineering department must abide by the academic regulations of the School of Graduate Studies (http://bulletin.case.edu/schoolofgraduatestudies/academicrequirements/) and the Case School of Engineering contained in the most recent issue of the Bulletin of Case Western Reserve University, and supplemented by the Department of Electrical, Computer, and Systems Engineering regulations.

PhD Degree Program Requirements
In order to successfully complete the PhD Degree Program, a student must satisfy the following requirements:

- Select a major dissertation subject area in Electrical Engineering, Computer Engineering, or Systems and Control Engineering
- Fulfill all PhD course requirements in the chosen major area (see individual degree requirements below)
- Have an approved Program of Study and complete the CWRU courses in the approved Program of Study with a cumulative grade point average of 3.25 or greater
- Successfully complete the PhD Qualifying Examination
- Successfully complete the PhD Proposal Defense
- Successfully complete and defend the PhD Dissertation
- Fulfill the PhD residency requirement

PhD Candidacy
The final consideration of whether to admit the student to PhD candidacy will be taken by the PhD Qualifying Committee (for Electrical Engineering and Computer Engineering students) or the student's dissertation guidance committee (for Systems and Control Engineering students) after the student has passed the PhD Qualifier. A written report on the results of the qualifier and PhD candidacy will be prepared by the committee and submitted to the Department Chairperson, who, in turn, will notify the School of Graduate Studies of the results.

PhD Proposal
After passing the Qualifier and being admitted to PhD candidacy, the PhD candidate is required to pass a Dissertation Proposal Exam on a timely basis, generally within one semester after being admitted to candidacy. This exam shall be administered by the student's dissertation guidance committee and consists of a written dissertation proposal and an oral presentation of the proposed dissertation research. As part of the oral presentation, the student will be expected to answer questions covering the proposed research as well as questions on related topics as deemed appropriate by the student's dissertation guidance committee. The written dissertation proposal must be received by the committee members at least ten days before the date scheduled for the oral exam and presentation. The Dissertation Proposal Exam, the PhD research, the final oral dissertation defense, and all other requirements in the student's PhD program of study must be completed within five years after the student is admitted to PhD candidacy.

The PhD Oral Defense
The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the ECSE Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

The PhD Residency Requirements
All PhD students shall fulfill the PhD residency requirements set forth by the Case School of Engineering and the School of Graduate Studies (http://bulletin.case.edu/schoolofgraduatestudies/academicpolicies/). Specifically, the PhD student is required either to register for at least 9 credit hours during each of two consecutive semesters or to engage in academic work (taking courses, assisting in course development and/or teaching, fully engaging in research, or some other scholarly activities) in at least six consecutive terms (fall, spring, or summer) between matriculation and a period not exceeding 5 years after the first credited hour of ECSE 701 Dissertation Ph.D. The period during a leave of absence cannot be counted to fulfill the residency requirement.

Electrical Engineering PhD
Course Requirements and Academic Program
Each Electrical Engineering PhD student is required to have an Academic Program, approved by the academic advisor, Department Chairperson, and Dean of Graduate Studies, that includes a minimum of 36 credit hours of coursework beyond the BS degree. At least 18 credit hours of coursework must be taken at CWRU. In addition, the student is also required to complete a minimum of 18 credit hours of ECSE 701 Dissertation Ph.D. to fulfill the requirement for PhD-level research. Acceptable courses include suitable CWRU courses at the 400 level or higher and approved graduate-level courses taken at other institutions. Students holding an MS degree in an appropriate field of study from CWRU or another degree-granting institution may apply up to 18 credit hours of coursework completed for their MS degree towards the aforementioned 36 credit hour requirement.

Each PhD student is required to have a fully-approved Academic Program before taking the PhD Qualifying examination and before registering for the final 18 credit hours of the program. The Academic Program shall be prepared by the student and approved by the research advisor or the permanent academic advisor in the case where the research advisor is not in the Department.
An Academic Program must meet the following requirements:

- A minimum of two courses in mathematics, statistics, or basic science.
- At least six approved courses from the student’s major area of study. At least 4 of these courses must be from within the ECSE department.
- Four additional courses that are not listed under the student’s major program area. These courses should satisfy the requirement for breadth in the student’s program of study.
- A minimum of 18 hours of PhD Dissertation research as noted by enrollment in and successful completion of ECSE 701 Dissertation Ph.D.
- Successful completion of ECSE 400T Graduate Teaching I, ECSE 500T Graduate Teaching II and ECSE 600T Graduate Teaching III.
- Successful completion of the ECSE 500 ECSE Colloquium requirement (see below)

The above represents the minimum course requirements beyond the BS degree. The total number of 3 credit hour courses in the Academic Program is at least twelve (12) beyond the BS level. The selection of these courses should be done with guidance from the student’s permanent academic advisor. Any additional courses may be in any one of the above categories as approved by the student’s advisor.

**ECSE Colloquium and Presentation Requirement**
The PhD program includes a colloquium and public presentation requirement.

**For those who matriculated during or after Fall 2012, the requirement has two parts:**

1. All PhD students are required to register for and pass ECSE 500 ECSE Colloquium for a total of three semesters of the PhD Program, and this is expected before Advancement to Candidacy. This is a 0 credit hour required course. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement, by submitting a written petition to the Graduate Studies Committee.

2. All PhD students must give a public presentation of their research, in addition to their PhD dissertation defense. This presentation must be given either at a research conference, in the ECSE seminar series, workshop presentations or similar presentations in a public venue. MS thesis and PhD dissertation defenses cannot be used to fulfill the public presentation requirement.

Additional details and the associated forms can be acquired from the ECSE Office of Student Affairs.

**For students who matriculated before Fall 2012, the requirement can be met in one of two ways:**

1. Completing the requirements detailed above, or
2. Passing 5 semesters of ECSE 500 ECSE Colloquium. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the ECSE Graduate Studies Committee.

**PhD Qualifying Examination**
A student shall be admitted to PhD candidacy only after they have passed the PhD Qualifying Examination. The Qualifying Exam is intended to test the students’ knowledge in the student’s chosen major program area of Electrical Engineering. The objectives of the exam are:

1. To assess the PhD student’s understanding of the fundamental concepts in Electrical Engineering as embodied in the respective graduate curriculum.
2. To ensure that the student have the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers

Full-time PhD students are recommended to take the PhD qualifier before the beginning of their third semester of full-time (or equivalent) enrollment, and must pass the exam within two years of being admitted to the program. For part-time students, the Qualifying Exam must be passed before more than 27 credit hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical, Computer, and Systems Engineering.

To pass the PhD Qualifier, the student must demonstrate proficiency in two parts:

**Part 1: Electrical Engineering**
The first part of the PhD Qualifier assesses the student’s fundamental knowledge and proficiency in Electrical Engineering:

**For students matriculating after 8/1/2014:**

Students must demonstrate competency in one of the following areas within electrical engineering in which the electrical engineering faculty have established research thrust areas:

1. Circuits and Instrumentation
2. Robotics
3. Micro- and Nano-systems

To demonstrate competency in one of these areas, the student must do one of the following:

1. take the course for that area and pass that course with a grade of A, or
2. pass a written exam for that specific area.

The designated courses for each of the areas are:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 422</td>
<td>Solid State Electronics II</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 426</td>
<td>MOS Integrated Circuit Design</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 489</td>
<td>Robotics I</td>
<td>3</td>
</tr>
</tbody>
</table>

In the event that a designated course is not offered within a reasonable period of time, the student may petition the faculty in electrical engineering to designate a suitable substitute.

A student failing to meet the requirements prescribed above may, with the support of their dissertation research advisor, petition the faculty for an oral exam. The oral exam will consist of a 30-minute presentation by the student to a 3-member examination committee made up of electrical engineering faculty. The topic will be drawn from the student’s area of interest as selected by their advisor and approved by the committee. The topic may not come directly from the student’s MS thesis conducted at CWRU or elsewhere.
A student has completed the PhD Qualifier in electrical engineering when:

1. they have successfully completed the aforementioned competency requirement,
2. a group of faculty within their selected research area has conducted a review of the student's academic record and determined that adequate progress has been made, and
3. the student has formally identified a dissertation advisor.

For students matriculating prior to 8/1/2014:

The written portion of the PhD Qualifier in Electrical Engineering is designed to assess a student's knowledge and understanding of topics fundamental to all electrical engineering students pursuing a doctorate in the field. The written exam will consist of questions at the advanced undergraduate level covering material from the three topic areas listed below. Courses currently in the Electrical Engineering undergraduate curriculum corresponding to a particular topic area are listed below:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>or ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
</tbody>
</table>

Exam problems will be limited to materials contained in the selected references as well as the aforementioned courses. Sample problems from previous exams as well as a list of relevant references are available upon request.

Students must show competency in all three tested areas. Upon recommendation of the faculty, a student showing marginal proficiency in one area may be required to correct this deficiency, for example, by taking an appropriate course (as determined by the faculty) and pass this course with at least a B grade or by serving as a teaching assistant of an appropriate course.

The written part of the Qualifying Exam for Electrical Engineering will be offered at least once a year during the month of January, prior to the beginning of the spring semester.

Part 2: Electrical Engineering

The second part of the PhD Qualifier shall be prepared and administered by the designated PhD Qualifying committee for students in the Electrical Engineering program. This exam will test the student on advanced topics in the student's major area of study as well as specialized topics relevant to the student's research area.

For students matriculating after 8/1/2014:

Does not apply

For students matriculating prior to 8/1/2014:

Only those students performing adequately on the written exam will advance to the oral portion of the qualifier. The exam will be administered by a three-member examination committee assembled from the ECSE faculty. The oral portion of the PhD Qualifier will consist of a two-part examination. The first part of the oral exam will consist of a 20-minute presentation by the student on a topic selected by the examination committee. The topic will be one that is well documented in the scientific/engineering literature. In selecting the topic, the examination committee will take into account the student's research interests, academic background, and experience in the field. The student will be given the topic 15 working days prior to the examination. The topic will be presented to the student in the form of a published paper or collection of papers.

The student will be required to demonstrate competency in the following areas:

1. the material directly covered by the paper(s),
2. the material covered in the important references in the paper(s), and
3. any relevant background material that is necessary for the fundamental understanding of the paper.

The second part of the oral exam will consist of a series of questions drawn from the topic areas covered by the written exam. As with the written exam, a student showing marginal proficiency during the oral exam may be asked to perform some sort of remediation at the discretion of the oral examination committee.

Computer Engineering PhD
Course Requirements and Academic Program

Each Computer Engineering PhD student is required to have an Academic Program, approved by the academic advisor, Department Chairperson, and Dean of Graduate Studies, that includes a minimum of 36 credit hours of coursework beyond the BS degree. At least 18 credit hours of coursework must be taken at CWRU. In addition, the student is also required to complete a minimum of 18 credit hours of ECSE 701 Dissertation Ph.D. to fulfill the requirement for Ph.D-level research. Acceptable courses include suitable CWRU courses at the 400 level or higher and approved graduate-level courses taken at other institutions. Students holding an MS degree in an appropriate field of study from CWRU or another degree-granting institution may apply up to 18 credit hours of coursework completed for their MS degree towards the aforementioned 36 credit hour requirement.

Each PhD student is required to have a fully-approved Academic Program before taking the PhD Qualifying examination and before registering for the final 18 credit hours of the program. The Academic Program shall be prepared by the student and approved by the research advisor or the permanent academic advisor in the case where the research advisor is not in the Department.

An Academic Program must meet the following requirements:

- A minimum of two courses in mathematics, statistics, or basic science.
- At least six approved courses from the student's major area of study. At least 4 of these courses must be from within the ECSE department.
- Four additional courses that are not listed under the student's major program area. These courses should satisfy the requirement for breadth in the student's program of study.
- A minimum of 18 hours of Ph.D. Dissertation research as noted by enrollment in and successful completion of ECSE 701 Dissertation Ph.D.
- Successful completion of ECSE 400T Graduate Teaching I, ECSE 500T Graduate Teaching II and ECSE 600T Graduate Teaching III.
- Successful completion of the ECSE 500 ECSE Colloquium requirement (see below)

The above represents the minimum course requirements beyond the BS degree. The total number of 3 credit hour courses in the Academic Program is at least twelve (12) beyond the BS level. The selection of these courses should be done with guidance from the student’s
permanent academic advisor. Any additional courses may be in any one of the above categories as approved by the student’s advisor.

**ECSE Colloquium and Presentation Requirement**

The PhD program includes a colloquium and public presentation requirement.

For those who matriculated during or after Fall 2012, the requirement has two parts:

1. All PhD students are required to register for and pass ECSE 500 ECSE Colloquium for a total of three semesters of the PhD Program, and this is expected before Advancement to Candidacy. This is a 0 credit hour required course. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the Graduate Studies Committee.

2. All PhD students must give a public presentation of their research, in addition to their PhD dissertation defense. This presentation must be given either at a research conference, in the ECSE seminar series, workshop presentations or similar presentations in a public venue. MS thesis and PhD dissertation defenses cannot be used to fulfill the public presentation requirement.

Additional details and the associated forms can be acquired from the ECSE Office of Student Affairs.

**For students who matriculated before Fall 2012, the requirement can be met in one of two ways:**

1. Completing the requirements detailed above, or

2. Passing 5 semesters of ECSE 500 ECSE Colloquium. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the ECSE Graduate Studies Committee.

**PhD Qualifying Examination**

A student shall be admitted to PhD candidacy only after they have passed the PhD Qualifying Examination. The Qualifying Exam is intended to test the students’ knowledge in the student’s chosen major program area of Computer Engineering. The objectives of the exam are:

1. To assess the PhD student’s understanding of the fundamental concepts in Computer Engineering as embodied in the respective graduate curriculum.

2. To ensure that the student has the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers.

Full-time PhD students are recommended to take the PhD qualifier before the beginning of their third semester of full-time (or equivalent) enrollment, and must pass the exam within two years of being admitted to the program. For part-time students, the Qualifying Exam must be passed before more than 27 credit hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical, Computer, and Systems Engineering.

To pass the PhD Qualifier, the student must demonstrate proficiency in two parts:

**Part 1: Computer Engineering**

Part 1 of the PhD Qualifier will consist of a written examination with questions drawn from several course areas listed below. At least three (3) topic areas must be pursued by the student for a complete qualifier. The exam style is a mini-project oriented, take home test that must be completed within a one week period.

<table>
<thead>
<tr>
<th>ECSE 315</th>
<th>Digital Systems Design</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 401</td>
<td>Digital Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 419</td>
<td>Computer System Architecture</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 485</td>
<td>VLSI Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 488</td>
<td>Embedded Systems Design</td>
<td>3</td>
</tr>
<tr>
<td>CDS 425</td>
<td>Computer Networks I</td>
<td>3</td>
</tr>
</tbody>
</table>

Additional topic areas may be assigned depending on the student interests and recommendations from their advisors.

If a student fails all three areas of the written examination, the entire exam must be taken again. If a student fails some areas, the faculty may elect to give another exam to the student in just the areas failed.

The written part of the Qualifying Exam for Computer Engineering will be offered at least once a year at the end of the spring semester.

**Part 2: Computer Engineering**

Part 2 will consist of an oral exam based on the areas of the written examination. However, the oral exam may be waived if the student has performed well in all three topic areas of the written exam.

**Systems and Control Engineering PhD**

**Course Requirements and Academic Program**

Each Systems and Control Engineering PhD student is required to have an Academic Program, approved by the academic advisor, Department Chairperson, and Dean of Graduate Studies, that includes a minimum of 36 credit hours of coursework beyond the BS degree. At least 18 credit hours of coursework must be taken at CWRU. In addition, the student is also required to complete a minimum of 18 credit hours of ECSE 701 Dissertation Ph.D. to fulfill the requirement for PhD-level research. Acceptable courses include suitable CWRU courses at the 400 level or higher and approved graduate-level courses taken at other institutions. Students holding an MS degree in an appropriate field of study from CWRU or another degree-granting institution may apply up to 18 credit hours of coursework completed for their MS degree towards the aforementioned 36 credit hour requirement.

Each PhD student is required to have a fully-approved Academic Program before taking the PhD Qualifying examination and before registering for the final 18 credit hours of the program. The Academic Program shall be prepared by the student and approved by the research advisor or the permanent academic advisor in the case where the research advisor is not in the Department.

**An Academic Program must meet the following requirements:**

- A minimum of two courses in mathematics, statistics, or basic science.
- At least six approved courses from the student's major area of study.
- At least 4 of these courses must be from within the ECSE department.
A student shall be admitted to PhD candidacy only after they have passed the PhD Qualifying Examination. For students who matriculated before Fall 2012, the requirement can be fulfilled by passing the examination before the beginning of their third semester of full-time enrollment, or the equivalent. For part-time students, the Qualifying Exam must be passed before more than 27 credit hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical, Computer, and Systems Engineering.

To pass the PhD Qualifier, the student must demonstrate proficiency in two parts:

1. All PhD students are required to register for and pass ECSE 500 ECSE Colloquium for a total of three semesters of the PhD Program, and this is expected before Advancement to Candidacy. This is a 0 credit hour required course. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the Graduate Studies Committee.

2. All PhD students must give a public presentation of their research, in addition to their PhD dissertation defense. This presentation must be given either at a research conference, in the ECSE seminar series, workshop presentations or similar presentations in a public venue. MS thesis and PhD dissertation defenses cannot be used to fulfill the public presentation requirement.

Additional details and the associated forms can be acquired from the ECSE Office of Student Affairs.

For those who matriculated during or after Fall 2012, the requirement has two parts:

1. Completing the requirements detailed above, or
2. Passing five semesters of ECSE 500 ECSE Colloquium. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the ECSE Graduate Studies Committee.

PhD Qualifying Examination
A student shall be admitted to PhD candidacy only after they have passed the PhD Qualifying Examination. The Qualifying Exam is intended to test the students' knowledge in the student's chosen major program area of Systems and Control Engineering. The objectives of the exam are:

1. To assess the student's understanding of the fundamental concepts in Systems and Control Engineering as embodied in the respective graduate curriculum.
2. To ensure that the student have the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers.

Full-time PhD students are recommended to take the PhD qualifier before the beginning of their third semester of full-time (or equivalent) enrollment, and must pass the exam within two years of being admitted to the program. For part-time students, the Qualifying Exam must be passed before more than 27 credit hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical, Computer, and Systems Engineering.

To ensure that the student have the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers.

For students who matriculated before Fall 2012, the requirement can be met in one of the following ways:

1. Completing the requirements detailed above, or
2. Passing five semesters of ECSE 500 ECSE Colloquium. Students, such as part-time students working in industry, may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the ECSE Graduate Studies Committee.

Part 1: Systems and Control Engineering
Students must show competency in control systems engineering, signals and systems, and systems analysis (optimization, simulation, stochastic modeling, and decision and economic analysis). Students must demonstrate proficiency in at least three of the following areas:

Control Systems

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 408</td>
<td>Introduction to Linear Systems</td>
<td>3</td>
</tr>
</tbody>
</table>

Optimization

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 346</td>
<td>Engineering Optimization</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 416</td>
<td>Convex Optimization for Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

Signal Processing

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 401</td>
<td>Digital Signal Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

Simulation and Discrete Event Systems

<table>
<thead>
<tr>
<th>Course Code</th>
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<tr>
<td>ECSE 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
<td>3</td>
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Stochastic Models and Decisions

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<tr>
<th>Course Code</th>
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<tr>
<td>ECSE 352</td>
<td>Engineering Economics and Decision Analysis</td>
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<tr>
<td>ECSE 452</td>
<td>Random Signals</td>
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To ensure that the student have the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers.

Full-time PhD students are recommended to take the PhD qualifier before the beginning of their third semester of full-time (or equivalent) enrollment, and must pass the exam within two years of being admitted to the program. For part-time students, the Qualifying Exam must be passed before more than 27 credit hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical, Computer, and Systems Engineering.

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Part 2: Systems and Control Engineering

A typical exam begins with a selection by the student’s dissertation guidance committee of 5-6 research articles relevant to the student’s research area. The students will be given 4 weeks to write a report answering questions formulated from those papers by the dissertation guidance committee. This will be followed within one week by an oral exam during which the student will give an oral presentation based on the report and answer questions from the dissertation guidance committee and other attending ECSE faculty. Questions will be based on the report as well as miscellaneous questions on advanced topics in Systems and Control Engineering as deemed appropriate by committee members and/or other attending faculty.

Facilities

Computer Facilities

The department computer facilities incorporate both Unix (primarily Linux) and Microsoft Windows-based operating systems on high-end computing workstations for education and research. A number of file, printing, database and authentication servers support these workstations, as well as the administrative functions of the department. Labs are primarily located in the Olin and Glennan buildings, but include Nord Hall, and are networked via the Case network.

The Case network is a state-of-the-art, high-speed fiber optic campus-wide computer network that interconnects laboratories, faculty and student offices, classrooms, and student residence halls. It is one of the largest fiber-to-desktop networks anywhere in the world. Every desktop has a 1 Gbps (gigabit per second) connection to a fault-tolerant 10 Gbps backbone. To complement the wired network, over 1,200 wireless access points (WAPs) are also deployed allowing anyone with a laptop or wireless enabled PDA to access resources from practically anywhere on campus.

Off-campus users, through the use of virtual private network (VPN) servers, can use their broadband connections to access many on-campus resources, as well as software, if they were physically connected to the Case network. The department and the university participate in the Internet2 and National Lambda Rail projects, which provide high-speed, inter-university network infrastructure allowing for enhanced collaboration between institutions. The Internet2 infrastructure allows students, faculty and staff alike the ability to enjoy extremely high-performance connections to other Internet2 member institutions.

Aside from services provided through a commodity Internet connection, Case network users can take advantage of numerous online databases such as EUCLIDplus, the University Libraries’ circulation and public access catalog, as well as Lexus-Nexus™ and various CD-ROM based dictionaries, thesauri, encyclopedias, and research databases. Many regional and national institutional library catalogs are accessible over the network, as well.

ECSE faculty are active users of the Microfabrication Laboratory and participants in the Advanced Platform Technology Center described under Interdisciplinary Research Centers.

Additional Department Facilities

Sally & Larry Sears Undergraduate Design Laboratory

This laboratory supports all departmental courses in circuits and includes a state-of-the-art lecture hall, a modernistic glass-walled lab, an electronics "store", and a student lounge and meeting area. Specialized lab space is available for senior projects and sponsored undergraduate programs. The lab is open to all undergraduates, and components are provided free of charge, so students can "play and tinker" with electronics and foster innovation and creativity. The laboratory provides access to PCs, oscilloscopes, signal generators, logic analyzers, and specialized equipment such as RF analyzers and generators. In addition, the lab includes full-time staff dedicated to the education, guidance and mentoring of undergraduates in the "art and practice" of hands-on engineering.

This is the central educational resource for students taking analog, digital, and mixed-signal courses in electronics, and has been supported by various corporations in addition to alumnus Larry Sears, a successful engineer and entrepreneur. Basic workstations consist of Windows-based computers equipped with LabView software, as well as Agilent 546xx oscilloscopes, 33120A Waveform Generators, 34401A Digital Multimeters, and E3631A power supplies. Advanced workstations are similarly configured, but with a wider variety of high-performance test equipment.

ECSE Undergraduate Computer Lab

This laboratory (recently renovated with major funding provided by Rockwell Automation) on the 8th floor of the Olin building is accompanied by a suite of instructor/TA offices and supports the freshman computing classes: ENGR 131 Elementary Computer Programming and ECSE 132 Introduction to Programming in Java. Thirty student Macintosh workstations with underlying UNIX operating systems are available for hands-on instruction and support the study of introductory programming at the university.

Nord Computer Laboratory

This is a general-purpose computer facility that is open 24 hours a day, to all students. The lab contains 50 PCs running Windows and four Apple Macintosh computers. Facilities for color printing, faxing, copying and scanning are provided. Special software includes PRO/Engineer, ChemCAD and Visual Studio. Blank CDs, floppy disks, transparencies and other supplies are available for purchase. Visit the website (https://engineering.case.edu/it/nord-computer-lab/) for more information.

Kevin Kranzusch Virtual Worlds (Gaming and Simulation) Laboratory

The Kevin Kranzusch Virtual Worlds Gaming and Simulation Laboratory provides software and hardware to support education and research in computer gaming and simulation activities within the Electrical, Computer, and Systems Engineering Department and the University at large. The lab has been leveraged to provide students with extensive game play opportunities and excellent, strongly experiential simulation and game development educational opportunities — primarily targeted to the ECSE undergraduate population.

The lab also stimulates large amounts of cross-disciplinary collaboration in both education and research. Simulation and visualization techniques are of great value in all science and engineering fields, and the lab is capable of supporting advanced applications of these techniques in real-time applications. In addition, interactive technologies and video games require substantial artistic resources, which has resulted in excellent opportunities for educational and research collaboration with the Cleveland Institute of Art (CIA), the School of Nursing, the Medical School, and the Psychology Department. Of particular note has been the Advanced Game Project course (ECSE 390 Advanced Game Development Project) taught jointly by CWRU and CIA for juniors and seniors. This course has been very popular and has provided truly excellent student game design and production experiences while receiving industrial and popular recognition and acclaim. In addition, an entry-level computer
game programming course (ECSE 290 Introduction to Computer Game Design and Implementation) is available for students who have taken both a Java-based programming course and a data structures course to provide an introduction to many of the technical aspects of computer game development. Many other courses in the department also use the lab as an important part of their curriculum including courses on computer graphics, artificial intelligence, simulation, digital signal processing, and control systems. The lab also supports research in the department requiring significant computational resources, e.g. GPU acceleration, VLSI simulation, etc.

A recent large donation for the lab has allowed for the update and renovation of the entire lab including the physical infrastructure (carpeting, furniture, etc.), the gaming PCs, and the gaming consoles. In addition, a new VR and AR room has been added to represent this new area connected strongly to computer gaming. The lab is now structured into a PC gaming area and an adjacent gaming console area, a VR/AR room, a portable gaming development room, and a team collaboration room.

The renovated lab includes the following primary equipment:

- 24 New Alienware PCs with Dell 27” 4K monitors
- 4 Sony Bravia Television monitors 75” 3DTV
- 2 Microsoft HoloLens AR Units
- 4 Oculus Rift VR units with Haptic Touch Input devices
- A 3D projector (and large wall screen) with 3D capability for common presentations
- 4 Xbox One Units with Xbox One controllers
- 4 PS4 Sony PlayStation units with controllers

Intelligent Networks & Systems Architecting (INSA) Research Laboratory

The Intelligent Networks & Systems Architecting (INSA) Research Laboratory is a state-of-the-art research facility dedicated to intelligent computer networks, systems engineering, design, and architecture. It includes optimization, simulation, artificial intelligence, visualization, and emulation. This lab has been partially supported by NASA’s Space Exploration programs for Human and Robotic Technology (H&RT). The INSA Lab is equipped with 10 high-performance workstations and 2 servers in a mixed Windows and Linux environment, with over 40 installed network interface cards providing connectivity to its wired and wireless research networks. It includes software packages such as GINO and LINDO, Arena simulation, ns2 and OPNET, as well as the STK satellite toolkit, artificial neural network, systems architecting and modeling, and statistical analysis and data management packages such as SPSS. The INSA Lab is also used for research in heterogeneous, sensor web, and mobile ad-hoc networks with space and battlefield applications.

VLSI/CAD Design Laboratory

This lab has been supported by the Semiconductor Research Corporation, NSF, AFRL, NASA, Synopsys, Mentor, and Sun Microsystems. This laboratory has a number of advanced UNIX/Linux workstations that run commercial CAD software tools for VLSI ASIC and microchip design, simulation and testing. The lab is currently being used to develop design and testing techniques for embedded system-on-chip (SoC).

Embedded Systems Laboratory

The Embedded Systems Laboratory is equipped with several Sun Blade Workstations running Solaris and Intel PCs running Linux. This lab has been recently equipped with advanced FPGA Virtex II prototype boards from Xilinx, including many Xilinx Virtex II FPGAs and Xilinx CAD tools for development work. A grant-in-aid from Synopsys has provided the Synopsys commercial CAD tools for software development and simulation. More recently, the lab has been equipped with many modern embedded platforms based on Raspberry Pi 3 and 4 models with numerous sensor devices. The lab has been also equipped with advanced embedded FPGA/ARM boards based on the Xilinx Zynq platform. This lab is equipped with NIOS FPGA boards from Altera, including software tools. Together with software CAD EDK tools, these modern equipment and tools will be of great help to students’ education and research work.

Mixed-Signal Integrated Circuit Laboratory

This research laboratory includes a cluster of Windows workstations and a UNIX server with integrated circuit design software (Cadence Custom IC Bundle), as well as a variety of equipment used in the characterization of mixed-signal (analog and digital) integrated circuits, which are typically fabricated using the MOSIS foundry service. Test equipment includes an IC probe station, surface-mount soldering equipment, logic and network/spectrum analyzers, an assortment of digital oscilloscopes with sample rates up to 1 GHz, and a variety of function generators, multi-meters, and power supplies.

Microelectromechanical Systems (MEMS) Research Laboratory

The MEMS Research Laboratory is equipped for microfabrication processes that do not require a clean room environment. These include chemical-mechanical polishing (two systems), bulk silicon etching, aqueous chemical release of free-standing micromechanical components, and supercritical point drying. In addition to the fabrication capabilities, the lab is also well equipped for testing and evaluation of MEMS components as it houses wafer-scale probe stations, a vacuum probe station, a multipurpose vacuum chamber, and an interferometric load-deflection station. Two large (8 x 2 ft²) vibration isolated air tables are available for custom testing setups. The laboratory has a wide variety of electronic testing instruments, including a complete IV-CV testing setup.

BioMicroSystems Laboratory

This research laboratory focuses on developing wireless integrated circuits and microsystems for a variety of applications in biomedical and neural engineering. The laboratory contains several PC computers, software packages for design, simulation, and layout of high-performance, low-noise, analog/mixed-signal/RF circuits and systems, and testing/measurement equipment such as a power supply, arbitrary function generator, multichannel mixed-signal oscilloscope, data acquisition hardware, spectrum analyzer, potentiostat, and current source meter. Visit the website (http://www.mohsenilab-cwru.org/) for more information.

Emerging Materials Development and Evaluation Laboratory

The EMDE Laboratory is equipped with tooling useful in characterizing materials for MEMS applications. The laboratory contains a PC-based apparatus for load-deflection and burst testing of micromachined membranes, a custom-built test chamber for evaluation and reliability testing of MEMS-based pressure transducers and other membrane-based devices, a probe station for electrical characterization of micro-devices, a fume hood configured for wet chemical etching of Si, polymers, and a wide variety of metals, tooling for electroplating, an optical reflectometer, and a supercritical-point dryer for release of surface micromachined devices. The lab also has a PC with layout and finite element modeling
software for device design, fabrication process design, and analysis of testing data.

**Control and Energy Systems Center (CESC)**

The Control and Energy Systems Center (CESC) looks for new transformational research and engineering breakthroughs to build a better world, improving our industry, economy, energy, environment, water resources and society, all with sustainability and within an international collaboration framework. With an interdisciplinary and concurrent engineering approach, the CESC focuses on bridging the gap between fundamental and applied research in advanced control and systems engineering, with special emphasis on energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research foci are to gain knowledge and understanding on multi-input-multi-output physical worlds, nonlinear plants, distributed parameter systems, plants with non-minimum phase, time delay and/or uncertainty, etc., and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems. Applied research aims to develop advanced solutions with industrial partners, for practical control engineering problems in energy systems, multi-megawatt wind turbines, renewable energy plants, power system dynamics and control, grid integration, energy storage, power electronics, wastewater treatment plants, desalination systems, formation flying spacecraft, satellites with flexible appendages, heating systems, robotics, parallel kinematics, telescope control, etc. The Center was established in 2009 with the support of the Milton and Tamar Maltz Family Foundation and the Cleveland Foundation.

**Process Control Laboratory**

This laboratory contains process control pilot plants and computerized hardware for data acquisition and process control that is used for demonstrations, teaching, and research. This laboratory also has access to steam and compressed air for use in the pilot processes that include systems for flow and temperature control, level and temperature control, pH control, and pressure control plants.

**Dynamics and Control Laboratory**

This laboratory contains data acquisition and control devices, PLCs, electromechanical systems, and mechanical, pneumatic, and electrical laboratory experiments for demonstrations, teaching, and research. Particular systems include: AC/DC servo systems, multi-degree-of-freedom robotic systems, rectilinear and torsional multi-degree-of-freedom vibration systems, inverted pendulum, magnetic levitation system, and a PLC-controlled low-voltage AC smart grid demonstration system that includes conventional and renewable (wind and solar) generation, battery and compressed air energy storage, residential, commercial and industry loads, a capacitor bank for real-time power factor correction, and advanced sensing and controls implemented through an interconnected system of intelligent software agents.

**Medical Robotics and Computer Integrated Surgery (MeRCIS) Laboratory**

The Medical Robotics and Computer Integrated Surgical Systems Laboratory (MeRCIS) is equipped for research on medical robotics, advanced control systems, haptics, and human-machine interfaces. Specifically, the MeRCIS laboratory houses major equipment, computational resources, and software infrastructure to support: i) design, modeling, and simulation of robotic systems, specifically milli- and micro-robotic tools for medical applications, ii) design, modeling and simulation of high performance control systems, iii) design and analysis of haptic systems, iv) development of virtual environment-based medical training simulators, and v) modeling and simulation of complex biological systems.

The laboratory is equipped with state-of-the-art sensing, electronic measurement, and data acquisition equipment, as well as, some rare and unique resources available to support research on robotics and intelligent systems, with specific emphasis on medical robotics. The laboratory has an Intuitive Surgical daVinci™ IS1200 robotic surgical system. The system has been upgraded with an open interface electronics kit that converted the system into a ROS compatible open research platform (dVRK).

**Courses**

**ECSE 132. Introduction to Programming in Java. 3 Units.**

An introduction to modern programming language features, computer programming and algorithmic problem solving with an emphasis on the Java language. Computers and code compilation; conditional statements, subprograms, loops, methods; object-oriented design, inheritance and polymorphism, abstract classes and interfaces; types, type systems, generic types, abstract data types, strings, arrays, linked lists; software development, modular code design, unit testing; strings, text and file I/O; GUI components, GUI event handling; threads; comparison of Java to C, C++, and C#. Offered as CSDS 132 and ECSE 132. Counts for CAS Quantitative Reasoning Requirement.

**ECSE 216. Fundamental System Concepts. 3 Units.**

Develops framework for addressing problems in science and engineering that require an integrated, interdisciplinary approach, including the effective management of complexity and uncertainty. Introduces fundamental system concepts in an integrated framework. Properties and behavior of phenomena regardless of the physical implementation through a focus on the structure and logic of information flow. Systematic problem solving methodology using systems concepts. Recommended preparation: MATH 224.

**ECSE 233. Introduction to Data Structures. 4 Units.**

Different representations of data: lists, stacks and queues, trees, graphs, and files. Manipulation of data: searching and sorting, hashing, recursion and higher order functions. Abstract data types, templating, and the separation of interface and implementation. Introduction to asymptotic analysis. The Java language is used to illustrate the concepts and as an implementation vehicle throughout the course. Offered as CSDS 233 and ECSE 233. Prereq: CSDS 132 or ECSE 132 or EECS 132.

**ECSE 245. Electronic Circuits. 4 Units.**

ECSE 246. Signals and Systems. 4 Units.

ECSE 275. Fundamentals of Robotics. 4 Units.
The Fundamentals of Robotics course will expose students to fundamental principles of robotics. Students will explore high level conceptual foundations of robotics beginning with Branten vehicles and apply this knowledge to simulated and physical robot hardware in laboratory experiences and in a final project. Laboratory experiences will guide students through applying theory to practice increasingly complex tasks in a project oriented, group work environment. The course culminates in a robotics challenge project at the end of the semester. Topics covered are: sensors, actuators, kinematics, control, planning and programming. Programming languages and concepts (e.g., C++, object oriented programming) used in robotics will be introduced and used with modern robotics programming toolboxes and frameworks. Prior experience with these languages will not be necessary. Previous experience with robotics is not required for this course. Offered as CSDS 275 and ECSE 275. Prereq: (ENGR 131 or EEC 132) and PHYS 121 and MATH 121.

ECSE 281. Logic Design and Computer Organization. 4 Units.
Fundamentals of digital systems in terms of both computer organization and logic level design. Organization of digital computers; information representation; boolean algebra; analysis and synthesis of combinational and sequential circuits; datapaths and register transfers; instruction sets and assembly language; input/output and communication; memory. Offered as CSDS 281 and ECSE 281. Prereq: ENGR 131 or ECSE 132.

ECSE 290. Introduction to Computer Game Design and Implementation. 3 Units.
This class begins with an examination of the history of video games and of game design. Games will be examined in a systems context to understand gaming and game design fundamentals. Various topics relating directly to the implementation of computer games will be introduced including graphics, animation, artificial intelligence, user interfaces, the simulation of motion, sound generation, and networking. Extensive study of past and current computer games will be used to illustrate course concepts. Individual and group projects will be used throughout the semester to motivate, illustrate and demonstrate the course concepts and ideas. Group game development and implementation projects will culminate in classroom presentation and evaluation. Offered as CSDS 290 and ECSE 290. Prereq: EECS 132 or CSDS 132.

ECSE 296. Independent Projects. 1 - 3 Units.
Independent projects in Electrical Engineering, Computer Engineering and Systems Engineering. Recommended preparation: ENGR 131 or EECS/CSDS/ECSE 132. Prereq: Limited to freshmen and sophomore students.

ECSE 297. Special Topics. 1 - 3 Units.
Special topics in Electrical Engineering, Computer Engineering and Systems and Control Engineering. Prereq: Limited to freshmen and sophomores.

ECSE 301. Digital Logic Laboratory. 2 Units.
This course is an introductory experimental laboratory for digital networks. The course introduces students to the process of design, analysis, synthesis and implementation of digital networks. The course covers the design of combinational circuits, sequential networks, registers, counters, synchronous/asynchronous Finite State Machines, register based design, and arithmetic computational blocks. Prereq: EECS 281.

ECSE 302. Discrete Mathematics. 3 Units.
A general introduction to basic mathematical terminology and the techniques of abstract mathematics in the context of discrete mathematics. Topics introduced are mathematical reasoning, Boolean connectives, deduction, mathematical induction, sets, functions and relations, algorithms, graphs, combinatorial reasoning. Offered as CSDS 302, ECSE 302 and MATH 304. Prereq: MATH 122 or MATH 124 or MATH 126.

ECSE 303. Embedded Systems Design and Laboratory. 3 Units.
The purpose of this Course and Laboratory is to expose and train the students in modern embedded systems software and hardware design techniques and practices including networking and mobile connectivity. The rationale for the Course and Lab is based on the explosive growth of embedded systems in the industry, specifically industrial automation, aviation, surveillance, medical devices, but also common consumer products. The course topics cover a wide range of material as follows. Microcontroller systems based on the ARM processor. Essential components, memories, busses interfaces. Devices, peripherals, GPIOs, device drivers. Sensors and Actuators, A/D, D/A, DSP. Embedded Linux, kernels, kernel modules, compilers and assemblers. Libraries, and debugging facilities. The Lab will be based on common platforms such as Raspberry pi, Arduino, ARM embed, supported by a network of Linux workstations.

ECSE 304. Control Engineering I with Laboratory. 3 Units.
Analysis and design techniques for control applications. Linearization of nonlinear systems. Design specifications. Classical design methods: root locus, bode, nyquist. PID, lead, lag, lead-lag controller design. State space modeling, solution, controllability, observability and stability. Modeling and control demonstrations and experiments single-input/ single-output and multivariable systems. Control system analysis/design/implementation software. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246 or EMAE 350.

ECSE 305. Control Engineering I Laboratory. 1 Unit.
A laboratory course based on the material in ECSE 304. Modeling, simulation, and analysis using MATLAB. Physical experiments involving control of mechanical systems, process control systems, and design of PID controllers. Coreq: EECS 304.

ECSE 309. Electromagnetic Fields I. 3 Units.
Maxwell's integral and differential equations, boundary conditions, constitutive relations, energy conservation and Pointing vector, wave equation, plane waves, propagating waves and transmission lines, characteristic impedance, reflection coefficient and standing wave ratio, in-depth analysis of coaxial and strip lines, electro- and magneto-quasistatics, simple boundary value problems, correspondence between fields and circuit concepts, energy and forces. Prereq: PHYS 122 or PHYS 124. Prereq or Coreq: MATH 224.
ECSE 313. Signal Processing. 3 Units.
Fourier series and transforms. Analog and digital filters. Fast-Fourier transforms, sampling, and modulation for discrete time signals and systems. Consideration of stochastic signals and linear processing of stochastic signals using correlation functions and spectral analysis. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246.

ECSE 314. Computer Architecture. 3 Units.
This course provides students the opportunity to study and evaluate a modern computer architecture design. The course covers topics in fundamentals of computer design, performance, cost, instruction set design, processor implementation, control unit, pipelining, communication and network, memory hierarchy, computer arithmetic, input-output, and an introduction to RISC and super-scalar processors. Offered as CSDS 314 and ECSE 314. Prereq: EECS 281.

ECSE 315. Digital Systems Design. 4 Units.
This course gives students the ability to design modern digital circuits. The course covers topics in logic level analysis and synthesis, digital electronics: transistors, CMOS logic gates, CMOS lay-out, design metrics space, power, delay. Programmable logic (partitioning, routing), state machine analysis and synthesis, register transfer level block design, datapath, controllers, ASM charts, microsequencers, emulation and rapid prototyping, and switch/logic-level simulation. Prereq: ECSE 281.

ECSE 316. Wireless Communications. 3 Units.
This course introduces the fundamentals of wireless communications including backgrounds, important concepts, and cutting-edge technologies. In particular, the course focuses on interesting and important topics in wireless communications, such as (but not limited to): Overview of wireless communication networks and protocols, the cellular concept, system design fundamentals, brief introduction to wireless physical layer fundamentals, multiple access control protocols for wireless systems, wireless networking (routing/re routing, wireless TCP/IP), mobility management, call admission control and resource allocation, revolution/ evolution towards future generation wireless networks, overview of wireless mesh networks, mobile ad hoc networks and wireless sensor networks, and wireless security (optional). Offered as ECSE 316 and ECSE 414. Prereq: (EECS 351 or ECSE 351) with a C or better, or a Graduate student.

ECSE 317. Computer Design - FPGAs. 3 Units.
The aim is to expose the student to methodologies for systematic design of digital systems with emphasis on programmable logic implementations and prototyping. The course requires a number of hands-on experiments and an overall lab project. The lab involves a number of class lectures to familiarize the students with the modern design techniques based on VHDL/Verilog Hardware Design Languages, CAD tools, and FPGAs. Offered as ECSE 317 and ECSE 417. Prereq: EECS 281.

ECSE 318. VLSI/CAD. 4 Units.
With Very Large Scale Integration (VLSI) technology there is an increased need for Computer-Aided Design (CAD) techniques and tools to help in the design of large digital systems that deliver both performance and functionality. Such high performance tools are of great importance in the VLSI design process, both to perform functional, logical, and behavioral modeling and verification to aid the testing process. This course discusses the fundamentals in behavioral languages, both VHDL and Verilog, with hands-on experience. Prereq: EECS 281 and EECS 315.

ECSE 319. Applied Probability and Stochastic Processes for Biology. 3 Units.
Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using a combination of MATLAB, the R statistical package, MCell, and/or URDME, at the discretion of the instructor. Student projects will comprise a major part of the course. Offered as BIOL 319, ECSE 319, MATH 319, SYBB 319, BIOL 419, EBME 419, MATH 419, PHOL 419, and SYBB 419. Prereq: (MATH 224 or MATH 223) and (BIOL 300 or BIOL 306) and (MATH 201 or MATH 307).

ECSE 321. Semiconductor Electronic Devices. 4 Units.
Energy bands and charge carriers in semiconductors and their experimental verifications. Excess carriers in semiconductors. Principles of operation of semiconductor devices that rely on the electrical properties of semiconductor surfaces and junctions. Development of equivalent circuit models and performance limitations of these devices. Devices covered include: junctions, bipolar transistors, Schottky junctions, MOS capacitors, junction gate and MOS field effect transistors, optical devices such as photodetectors, light-emitting diodes, solar cells, and lasers. Prereq: PHYS 122. Prereq or Coreq: MATH 224.

ECSE 322. Integrated Circuits and Electronic Devices. 3 Units.
Technology of monolithic integrated circuits and devices, including crystal growth and doping, photolithography, vacuum technology, metallization, wet etching, thin film basics, oxidation, diffusion, ion implantation, epitaxy, chemical vapor deposition, plasma processing, and micromachining. Basics of semiconductor devices including junction diodes, bipolar junction transistors, and field effect transistors. Prereq: PHYS 122. Prereq or Coreq: MATH 224.
ECSE 324. Modeling and Simulation of Continuous Dynamical Systems. 3 Units.
This course examines the computer-based modeling and simulation of continuous dynamical system behavior in a variety of systems including electric power systems, industrial control systems, and signal processing that are represented by a set of differential equations need to be solved numerically in order to compute and represent their behavior for study. In addition to these applications, there are many other important applications of these tools in computer games, virtual worlds, weather forecasting, and population models, to name a few examples. Numerical integration techniques are developed to perform these computations. Multiple computational engines such as Matlab, Simulink, Unity, and physics engines etc. are also examined as examples of commonly used software to solve for and visualize continuous-time system behavior.

The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide motivation and a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: MATH 224.

ECSE 326. Instrumentation Electronics. 3 Units.
A second course in instrumentation with emphasis on sensor interface electronics. General concepts in measurement systems, including accuracy, precision, sensitivity, linearity, and resolution. The physics and modeling of resistive, reactive, self-generating, and direct-digital sensors. Signal conditioning for same, including bridge circuits, coherent detectors, and a variety of amplifier topologies: differential, instrumentation, charge, and transimpedance. Noise and drift in amplifiers and resistors. Practical issues of interference, including grounding, shielding, supply/return, and isolation amplifiers. Prereq: ENGR 210 and (EECS 246, EBME 308 or EMAE 350).

ECSE 329. Introduction to Nanomaterials: Material Synthesis, Properties and Device Applications. 3 Units.
The behavior of nanoscale materials is close, to atomic behavior rather than that of bulk materials. The growth of nanomaterials, such as quantum dots, has the tendency to be viewed as an art rather than science. These nanostructures have changed our view of Nature. This course is designed to provide an introduction to nanomaterials and devices to both senior undergraduate and graduate students in engineering. Topics covered include an introduction to growth issues, quantum mechanics, quantization of electronic energy levels in periodic potentials, tunneling, distribution functions and density of states, optical and electronic properties, and devices. Offered as ECSE 329 and ECSE 429. Coreq: EECS 309.

ECSE 337. Compiler Design. 4 Units.
Design and implementation of compilers and other language processors. Scanners and lexical analysis; regular expressions and finite automata; scanner generators; parsers and syntax analysis; context free grammars; parser generators; semantic analysis; intermediate code generation; runtime environments; code generation; machine independent optimizations; data flow and dependence analysis. There will be a significant programming project involving the use of compiler tools and software development tools and techniques. Offered as CSDS 337 and ECSE 337. Prereq: (CSDS 233 or ECSE 233 or EECS 233) and (CSDS 281 or ECSE 281 or EECS 281).

ECSE 338. Intro to Operating Systems and Concurrent Programming. 4 Units.
Intro to OS: OS Structures, processes, threads, CPU scheduling, deadlocks, memory management, file system implementations, virtual machines, cloud computing. Concurrent programming: fork, join, concurrent statement, critical section problem, safety and liveness properties of concurrent programs, process synchronization algorithms, semaphores, monitors. UNIX systems programming: system calls, UNIX System V IPCs, threads, RPCs, shell programming. Offered as CSDS 338, ECSE, 338, CSDS 338N and ECSE 338N. Prereq: Computer Science Major or Minor and (CSDS 233 or ECSE 233 or EECS 233) with a C or higher.

ECSE 338N. Intro to Operating Systems and Concurrent Programming. 4 Units.
Intro to OS: OS Structures, processes, threads, CPU scheduling, deadlocks, memory management, file system implementations, virtual machines, cloud computing. Concurrent programming: fork, join, concurrent statement, critical section problem, safety and liveness properties of concurrent programs, process synchronization algorithms, semaphores, monitors. UNIX systems programming: system calls, UNIX System V IPCs, threads, RPCs, shell programming. Offered as CSDS 338, ECSE, 338, CSDS 338N and ECSE 338N. Prereq: (CSDS 233 or ECSE 233 or EECS 233) with a C or higher.

ECSE 342. Introduction to Global Issues. 3 Units.
This systems course is based on the paradigm of the world as a complex system. Global issues such as population, world trade and financial markets, resources (energy, water, land), global climate change, and others are considered with particular emphasis put on their mutual interdependence. A reasoning support computer system which contains extensive data and a family of models is used for future assessment. Students are engaged in individual, custom-tailored, projects of creating conditions for a desirable or sustainable future based on data and scientific knowledge available. Students at CWRU will interact with students from fifteen universities that have been strategically selected in order to give global coverage to UNESCO'S Global-problematique Education Network Initiative (GENIe) in joint, participatory scenario analysis via the internet.
ECSE 342I. Global Issues, Health, & Sustainability in India. 3 Units.
Global Issues, Health, & Sustainability in India is an interdisciplinary social work and engineering collaboration that includes a short-term cross-cultural immersion. This course brings together social work (knowledge, values, and skills) and health care (promotion, education, and community) perspectives to the understanding of technical project assessment, selection, planning and implementation in India. The course is also designed to help students understand culturally relevant community engagement strategies to ensure project acceptance in underserved and developing communities. Many field sites will be visited in order to observe first-hand the community assessment and development of projects that engineers implement. An example of these projects could include infrastructure to support green energy and water (resource planning, development, conservation, and sanitation). This study abroad course will acquaint students with history and culture of India, its social, political and economic development and the impact it has on health and the delivery of social services. Participants will learn about factors affecting the abilities to reach, treat, educate, and equip communities to improve health outcomes. Engineering students will learn the quantitative aspects using a paradigm of hierarchical systems, mathematical modeling, and scenario analysis using a ‘reasoning support’ system. Together the engineering, social work, and health sciences students in disciplinary-balanced teams will jointly work on real and meaningful projects marrying the descriptive scenarios (that is the ‘subjective’ aspect) with the numerical scenario analysis based on mathematical modeling (or ‘objective’ aspect) to form a coherent view of the future. The course will be taught using both lecture and experiential modalities. Engineering students will conduct computer modeling work. Along with visiting a variety of governmental and non-governmental institutions, organizations and projects, students will visit historical sites and attend cultural events. Offered as ECSE 342I and SASS 375I. Counts for CAS Global & Cultural Diversity Requirement.

ECSE 344. Electronic Analysis and Design. 3 Units.
The design and analysis of real-world circuits. Topics include: junction diodes, non-ideal op-amp models, characteristics and models for large and small signal operation of bipolar junction transistors (BJTs) and field effect transistors (FETs), selection of operating point and biasing for BJT and FET amplifiers. Hybrid-pi model and other advanced circuit models, cascaded amplifiers, negative feedback, differential amplifiers, oscillators, tuned circuits, and phase-locked loops. Computers will be extensively used to model circuits. Selected experiments and/or laboratory projects. Prereq: EECS 245.

ECSE 346. Engineering Optimization. 3 Units.
Optimization techniques including linear programming and extensions; transportation and assignment problems; network flow optimization; quadratic, integer, and separable programming; geometric programming; and dynamic programming. Nonlinear optimization topics: optimality criteria, gradient and other practical unconstrained and constrained methods. Computer applications using engineering and business case studies. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Recommended preparation: MATH 201.

ECSE 350. Operations and Systems Design. 3 Units.
Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and time series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queuing models, simulation, and artificial intelligence.

ECSE 351. Communications and Signal Analysis. 3 Units.
Fourier transform analysis and sampling of signals. AM, FM and SS modulation and other modulation methods such as pulse code, delta, pulse position, PSK and FSK. Detection, multiplexing, performance evaluation in terms of signal-to-noise ratio and bandwidth requirements. Prereq: EECS 246 or requisites not met permission.

ECSE 352. Engineering Economics and Decision Analysis. 3 Units.
Economic analysis of engineering projects, focusing on financial decisions concerning capital investments. Present worth, annual worth, internal rate of return, benefit/cost ratio. Replacement and abandonment policies, effects of taxes, and inflation. Decision making under risk and uncertainty. Decision trees. Value of information. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course.

ECSE 354. Digital Communications. 3 Units.

ECSE 360. Manufacturing and Automated Systems. 3 Units.
Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as ECSE 360 and ECSE 460.

ECSE 366. Computer Graphics. 3 Units.
Theory and practice of computer graphics: object and environment representation including coordinate transformations image extraction including perspective, hidden surface, and shading algorithms; and interaction. Covers a wide range of graphic display devices and systems with emphasis in interactive shaded graphics. Offered as CSDS 366, ECSE 366, CSDS 466 and ECSE 466. Prereq: EECS 233.
ECSE 368. Power System Analysis I. 3 Units.
This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as ECSE 368 and ECSE 468. Prereq: ECSE 245.

ECSE 369. Power System Analysis II. 3 Units.
This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as ECSE 369 and ECSE 469. Prereq: ECSE 368.

ECSE 370. Smart Grid. 3 Units.
This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as ECSE 370 and ECSE 470. Prereq: ECES 368.

ECSE 371. Applied Circuit Design. 4 Units.
This course will consist of lectures and lab projects designed to provide students with an opportunity to consolidate their theoretical knowledge of electronics and to acquaint them with the art and practice of circuit and product design. The lectures will cover electrical and electronic circuits and many electronic and electrical devices and applications. Examples include mixed-signal circuits, power electronics, magnetic and piezo components, gas discharge devices, sensors, motors and generators, and power systems. In addition, there will be discussion of professional topics such as regulatory agencies, manufacturing, testing, reliability, and product cost. Weekly labs will be true “design” opportunities representing real-world applications. A specification or functional description will be provided, and the students will design the circuit, select all components, construct a breadboard, and test. The objective will be functional, pragmatic, cost-effective designs. Prereq: ECSE 245.

ECSE 372. Introduction to Distribution Systems. 3 Units.
Introduction to Distribution Systems provides students with a fundamental understanding of distribution power system configurations, equipment and loads. It also provides a detailed review of distributed energy resources and their impacts on utility distribution systems. Since today’s distribution utilities are facing the challenge of managing a distribution network made up of assets from proven and mature technologies while integrating new technologies this course will also discuss a concept of smart grid and its application to distribution systems. The first part of the course reviews the fundamental methods used in the steady state analysis of AC circuits as applied to power distribution systems following by the steady-state modeling of electric power distribution systems. The second part of the course introduces fundamental analysis of electric power distribution systems such as power flow, state estimation, and fault calculation and discusses concerns such as reliability, power quality and voltage regulation. Offered as EECS 372 and EECS 472. Prereq: PHYS 122 and MATH 224.

ECSE 373. Modern Robot Programming. 3 Units.
The goal of this course is to learn modern methods for building up robot capabilities using the Robot Operating System (ROS). Through a sequence of assignments, students learn how to write software to control both simulated and physical robots. Material includes: interfacing software to robot I/O; path and trajectory planning for robot arms; object identification and localization from 3-D sensing; manipulation planning; and development of graphical interfaces for supervisory robot control. Laboratory assignments are scheduled in small groups to explore implementations on specific robots. Graduate students will also perform an independent project. Offered as CSDS 373, ECSE 373, CSDS 473 and ECSE 473. Prereq: ENGR 131 or EECS 132. Coreq: ECES 373L.

ECSE 374. Advanced Control and Energy Systems. 3 Units.
This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as ECSE 374 and ECSE 474. Prereq: EECS 304.

ECSE 375. Applied Control. 3 Units.
This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS/ECSE 374 or EECS/ECSE 474. Offered as ECSE 375 and ECSE 475. Prereq: EECS 304 or Requisites Not Met permission.
ECSE 376. Mobile Robotics. 4 Units.
Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Offered as CSDS 376 and ECSE 376. Prereq: ECSE 373 or ECSE 473.

ECSE 377. Introduction to Connected Devices. 3 Units.
Introduction to Connected Devices (e.g., Internet of Things). Undergraduates work in pairs to build a complete connected-device system, an embedded device with wireless networking, cloud and web, and mobile, and then develop hands-on experience with systems-level aspects of the connected-device system, including analytics, remote firmware update, load testing, and essential security. Students learn about current architectures, languages, and technologies, such as Pub/Sub (MQTT), Python, Objective-C, Python Django, JavaScript, HTML/CSS, and Bluetooth Low Energy. Offered as CSDS 377 and ECSE 377.

ECSE 379. Introduction to Relay Protection. 3 Units.
Protection does not mean prevention, but rather, minimizing the duration of the trouble and limiting the damage, outage time, and related problems that may result otherwise. Introduction to Relay Protection introduces the power system protection, including basic fundamental understanding of relaying, common protection methods and relay applications. The first part of the course reviews the technical tools of the relay engineering (phasors, polarity and symmetrical components), fault analyzes, protection fundamentals and basic design principles. The second part of the course focuses on the line, transformer, bus, generation and motor protection. The course will be accompanied by relay protection laboratory where students will have hands on experience with main types of protective relays. Offered as ECSE 379 and ECS3 479. Prereq: MATH 224 and PHYS 122.

ECSE 386. Quantum Computing, Information, and Devices. 3 Units.
An introduction to the math, physics, engineering, and computer science underlying the rapidly emerging fields of quantum computing, quantum information, and quantum devices. The course is taught by a group of faculty from physics, engineering, computer science, and math, and is geared towards students with diverse backgrounds and interests in these fields. Students will select a concentration in one of these four areas, and the coursework, while still covering all topics, will be adjusted to focus on the selected area in the most detail. Note that the listed prerequisites depend on choice of concentration. Topics will include: 1. (Mathematics) Introduction to linear algebra, convex geometry, fundamental theory of quantum information. 2. (Physics) Introduction to the quantum mechanics of two-level systems (qubits). Survey of physics and materials for qubit technologies. 3. (Computer Science) Basic quantum gates and circuits, introduction to the theory of algorithms, survey of quantum algorithms. 4. (Engineering) Quantum architectures, mapping algorithms onto circuits. The course consists of lectures, homework, and group projects. Group projects will aim to synthesize the diverse backgrounds of the students and instructors to capture the interdisciplinary nature of the field. Students taking the course for graduate credit will complete an additional literature research project and presentation, in addition to enhanced problem sets. Offered as CSDS 386, CSDS 486, ECSE 386, ECSE 486, MATH 386, MATH 486, PHYS 386, and PHYS 486. Prereq: (CSDS 281 or ECSE 281) and (ENGR 131 or CSDS 132 or ECSE 132) and (MATH 223 or MATH 227) and (MATH 224 or MATH 228) and (PHYS 122 or PHYS 124).

ECSE 390. Advanced Game Development Project. 3 Units.
This game development project course will bring together an interdisciplinary group of students in the fields of engineering, computer science, and art to focus on the design and development of a complete, fully functioning computer game as an interdisciplinary team. The student teams are given complete liberty to design their own fully functional games from their original concept to a playable game published in an online marketplace. Student teams will experience the entire game development cycle as they execute their projects. Responsibilities include creating a game idea, writing a story, developing the artwork, designing characters, implementing music and sound effects, programming and testing the game, and publishing the final project. Students enrolled in 487 will develop a healthcare or education virtual environment or video game in collaboration with a mentor who has expertise in the chosen area. Offered as CSDS 390, ECSE 390, CSDS 487, and ECSE 487. Prereq: EEC 233 and EEC 290.

ECSE 394. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended preparation: MATH 201 or MATH 307. Offered as MATH 394, CSDS 394, ECSE 394, MATH 494, CSDS 494 and ECSE 494. Prereq: MATH 223 and MATH 380 or requisites not met permission.

ECSE 396. Independent Projects. 1 - 6 Units.

ECSE 397. Special Topics. 1 - 6 Units.
Special topics in Computer Engineering, Electrical Engineering, and Systems and Control Engineering. Prereq: Limited to juniors and seniors.

ECSE 398. Engineering Projects I. 4 Units.
Capstone course for electrical, computer, and systems and control engineering seniors. Material from previous and concurrent courses used to solve engineering design problems. Professional engineering topics such as project management, engineering design, communications, multidisciplinary teaming, and professional ethics. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Scheduled formal project presentations during last week of classes. Counts as SAGES Senior Capstone. Prereq: Senior Standing. Prereq or Coreq: ENGR 398 and ENGL 398.

ECSE 399. Engineering Projects II. 3 Units.
Continuation of ECSE 398. Material from previous and concurrent courses applied to engineering design and research. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Prereq: Senior Standing.
ECSE 400T. Graduate Teaching I. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, tutoring students. Recommended preparation: Ph.D. student in ECSE department.

ECSE 401. Digital Signal Processing. 3 Units.

ECSE 404. Digital Control Systems. 3 Units.
Analysis and design techniques for computer based control systems. Sampling, hybrid continuous-time/discrete-time system modeling; sampled data and state space representations, controllability, observability and stability, transformation of analog controllers, design of deadbeat and state feedback controllers; pole placement controllers based on input/output models, introduction to model identification, optimal control and adaptive control. Recommended preparation: EEECS/ECE 304 or equivalent.

In this course, money and profit as measures of “goodness” in engineering design are studied. Methods for economic analysis of capital investments are developed and the financial evaluation of machinery, manufacturing processes, buildings, and personnel development, and other long-lived investments is emphasized. Optimization methods and decision analysis techniques are examined to identify economically attractive alternatives. Basic concepts of cost accounting are also covered. Topics include: economics criteria for comparing projects: present worth, annual worth analysis; depreciation and taxation; retirement and replacement; effect of inflation and escalation on economic evaluations; case studies; use of optimization methods to evaluate many alternatives; decision analysis; accounting fundamentals: income and balance sheets; cost accounting. Offered as ECSE 407 and EPOM 407.

ECSE 408. Introduction to Linear Systems. 3 Units.

ECSE 410. Mobile Health (mHealth) Technology. 3 Units.
Advances in communications, computer, and medical technology have facilitated the practice of personalized health, which utilizes sensory computational communication systems to support improved and more personalized healthcare and healthy lifestyle choices. The current proliferation of broadband wireless services, along with more powerful and convenient handheld devices, is helping to introduce real-time monitoring and guidance for a wide array of patients. Indeed, a large research community and a nascent industry is beginning to connect medical care with technology developers, vendors of wireless and sensing hardware systems, network service providers, and enterprise data management communities. Students in the course and labs will explore cutting-edge technologies in 1) information technologies and 2) healthcare/medical applications, through lectures, lab assignments, exams, presentations, and final projects. The overall course objectives are to introduce electrical engineering, computer engineering, and computer science students the fundamentals of wearable sensors, mobile health informatics, big data analysis, telehealthcare security & privacy, and human computer interaction considerations. Prereq: MS and PhD student only.

ECSE 411. Applied Engineering Statistics. 3 Units.
In this course a combination of lectures, demonstrations, case studies, and individual and group computer problems provides an intensive introduction to fundamental concepts, applications and the practice of contemporary engineering statistics. Each topic is introduced through realistic sample problems to be solved first by using standard spreadsheet programs and then using more sophisticated software packages. Primary attention is given to teaching the fundamental concepts underlying standard analysis methods. Offered as EPOM 405 and ECSE 411.

ECSE 413. Nonlinear Systems I. 3 Units.
This course will provide an introduction to techniques used for the analysis of nonlinear dynamic systems. Topics will include existence and uniqueness of solutions, phase plane analysis of two dimensional systems including Poincare-Bendixson, describing functions for single-input single-output systems, averaging methods, bifurcation theory, stability, and an introduction to the study of complicated dynamics and chaos. Recommended preparation: Concurrent enrollment in ECSE 408.

ECSE 414. Wireless Communications. 3 Units.
This course introduces the fundamentals of wireless communications including backgrounds, important concepts, and cutting-edge technologies. In particular, the course focuses on interesting and important topics in wireless communications, such as (but not limited to): Overview of wireless communication networks and protocols, the cellular concept, system design fundamentals, brief introduction to wireless physical layer fundamentals, multiple access control protocols for wireless systems, wireless networking (routing/rerouting, wireless TCP/IP), mobility management, call admission control and resource allocation, revolution/evolution towards future generation wireless networks, overview of wireless mesh networks, mobile ad hoc networks and wireless sensor networks, and wireless security (optional). Offered as ECSE 316 and ECSE 414. Prereq: Graduate student or (EECS 351 or ECSE 351) with a C or better.

ECSE 415. Integrated Circuit Technology I. 3 Units.
ECSE 416. Convex Optimization for Engineering. 3 Units.
This course will focus on the development of a working knowledge and skills to recognize, formulate, and solve convex optimization problems that are so prevalent in engineering. Applications in control systems; parameter and state estimation; signal processing; communications and networks; circuit design; data modeling and analysis; data mining including clustering and classification; and combinatorial and global optimization will be highlighted. New reliable and efficient methods, particular those based on interior-point methods and other special methods to solve convex optimization problems will be emphasized. Implementation issues will also be underscored. Recommended preparation: MATH 201 or equivalent.

ECSE 417. Computer Design - FPGAs. 3 Units.
The aim is to expose the student to methodologies for systematic design of digital systems with emphasis on programmable logic implementations and prototyping. The course requires a number of hands-on experiments and an overall lab project. The lab involves a number of class lectures to familiarize the students with the modern design techniques based on VHDL/Verilog Hardware Design Languages, CAD tools, and FPGAs. Offered as ECSE 317 and ECSE 417.

ECSE 418. System Identification and Adaptive Control. 3 Units.

ECSE 419. Computer System Architecture. 3 Units.
Interaction between computer systems hardware and software. Pipeline techniques - instruction pipelines - arithmetic pipelines. Instruction level parallelism. Cache mechanism. I/O structures. Examples taken from existing computer systems.

ECSE 422. Solid State Electronics II. 3 Units.

ECSE 426. MOS Integrated Circuit Design. 3 Units.

ECSE 427. Optoelectronic and Photonic Devices. 3 Units.
In this course, we will study the optical transitions, absorptions, and gains in semiconductors. We will discuss the optical processes in semiconductor bulk as well as low dimensional structures such as quantum well and quantum dot. The fundamentals, technologies and applications of important optoelectronic devices (e.g., light-emitting diodes, semiconductor lasers, solar cells and photo-detectors) will be introduced. We will learn the current state-of-the-art of these devices. Recommended preparation: EECS/ECSE 321.

ECSE 429. Introduction to Nanomaterials: Material Synthesis, Properties and Device Applications. 3 Units.
The behavior of nanoscale materials is close, to atomic behavior rather than that of bulk materials. The growth of nanomaterials, such as quantum dots, has the tendency to be viewed as an art rather than science. These nanostructures have changed our view of Nature. This course is designed to provide an introduction to nanomaterials and devices to both senior undergraduate and graduate students in engineering. Topics covered include an introduction to growth issues, quantum mechanics, quantization of electronic energy levels in periodic potentials, tunneling, distribution functions and density of states, optical and electronic properties, and devices. Offered as ECSE 329 and ECSE 429.

ECSE 434. Microsystems Technology. 3 Units.
This course provides an overarching coverage of microsystems technology, which is rooted in micro-electromechanical systems (MEMS). It covers the convergence of sensors and actuators, with wireless communications, computing and (social) networks. Microsystems incorporate sensors and actuators to interface computing with its physical environment-enabling perception and control. Microsystems are key enablers of smartphones, wearables, drones, robots, cars, aircrafts, weapons, etc. Recommended preparation: EECS/ECSE 322.

ECSE 438. High Performance Computing. 3 Units.
High performance computing (HPC) leverages parallel processing in order to maximize speed and throughput. This hands-on course will cover theoretical and practical aspects of HPC. Theoretical concepts covered include computer architecture, parallel programming, and performance optimization. Practical applications will be discussed from various information and scientific fields. Practical considerations will include HPC job management and Unix scripting. Weekly assessments and a course project will be required. Offered as CSDS 438 and ECSE 438. Prereq: EECS 233 or graduate standing.

ECSE 443. Flexible Electronics. 3 Units.
Learning about flexible and stretchable electronics from materials to applications. Covering organic and inorganic semiconductors, vacuum and solution-based metal-oxide semiconductors, nanomembranes and nanocrystals, conductors and insulators, flexible and ultra-high-resolution displays, lightemitting transistors, organic and inorganic photovoltaics, large-area imagers and sensors, non-volatile memories and radio-frequency identification tags. Discussing applications of flexible, stretchable and large-area electronics as part of the foregoing topics. Recommended preparation: EECS/ECSE 322.

ECSE 450. Operations and Systems Design. 3 Units.
Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and times series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queuing models, simulation, and artificial intelligence.
ECSE 452. Random Signals. 3 Units.

ECSE 460. Manufacturing and Automated Systems. 3 Units.
Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as ECSE 360 and ECSE 460.

ECSE 465. Computer Vision. 3 Units.
The goal of computer vision is to create visual systems that recognize objects and recover structures in complex 3D scenes. This course emphasizes both the science behind our understanding of the fundamental problems in vision and the engineering that develops mathematical models and inference algorithms to solve these problems. Specific topics include feature detection, matching, and classification; visual representations and dimensionality reduction; motion detection and optical flow; image segmentation; depth perception, multi-view geometry, and 3D reconstruction; shape and surface perception; visual scene analysis and object recognition. Offered as CSDS 465 and ECSE 465.

ECSE 466. Computer Graphics. 3 Units.
Theory and practice of computer graphics: object and environment representation including coordinate transformations image extraction including perspective, hidden surface, and shading algorithms; and interaction. Covers a wide range of graphic display devices and systems with emphasis in interactive shaded graphics. Offered as CSDS 366, ECSE 366, CSDS 466 and ECSE 466. Prereq: Graduate standing or Requisites Not Met permission.

ECSE 467. Commercialization and Intellectual Property Management. 3 Units.
This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two laws students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 367, GENE 467, EBME 467 and ECSE 467.

ECSE 468. Power System Analysis I. 3 Units.
This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as ECSE 368 and ECSE 468. Prereq: EECS 245.

ECSE 469. Power System Analysis II. 3 Units.
This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as ECSE 369 and ECSE 469. Prereq: EECS 368.
ECSE 470. Smart Grid. 3 Units.
This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving process made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as ECSE 370 and ECSE 470. Prereq: ECES 368.

ECSE 472. Introduction to Distribution Systems. 3 Units.
Introduction to Distribution Systems provides students with a fundamental understanding of distribution power system configurations, equipment and loads. It also provides a detailed review of distributed energy resources and their impacts on utility distribution systems. Since today's distribution utilities are facing the challenge of managing a distribution network made up of assets from proven and mature technologies while integrating new technologies this course will also discuss a concept of smart grid and its application to distribution systems. The first part of the course reviews the fundamental methods used in the steady state analysis of AC circuits as applied to power distribution systems following by the steady-state modeling of electric power distribution systems. The second part of the course introduces fundamental analysis of electric power distribution systems such as power flow, state estimation, and fault calculation and discusses concerns such as reliability, power quality and voltage regulation. Offered as EECS 372 and ECES 472. Prereq: Graduate student standing.

ECSE 473. Modern Robot Programming. 3 Units.
The goal of this course is to learn modern methods for building up robot capabilities using the Robot Operating System (ROS). Through a sequence of assignments, students learn how to write software to control both simulated and physical robots. Material includes: interfacing software to robot I/O; path and trajectory planning for robot arms; object identification and localization from 3-D sensing; manipulation planning; and development of graphical interfaces for supervisory robot control. Laboratory assignments are scheduled in small groups to explore implementations on specific robots. Graduate students will also perform an independent project. Offered as CSDS 373, ECSE 373, CSDS 473 and ECSE 473. Prereq: ENGR 131 or ECES 132.

ECSE 474. Advanced Control and Energy Systems. 3 Units.
This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as ECSE 374 and ECSE 474. Prereq: EECS 304.

ECSE 475. Applied Control. 3 Units.
This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS/ECSE 374 or EECS/ECSE 474. Offered as ECSE 375 and ECSE 475. Prereq: EECS 304 or Requisites Not Met permission.

ECSE 476. Mobile Robotics. 3 Units.
Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Offered as CSDS 476 and ECSE 476. Prereq: EECS 373 or EECS 473.

ECSE 477. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and neural networks, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, CSDS 478, EBME 478, ECSE 478, MATH 478 and NEUR 478.

ECSE 479. Introduction to Relay Protection. 3 Units.
Protection does not mean prevention, but rather, minimizing the duration of the trouble and limiting the damage, outage time, and related problems that may result otherwise. Introduction to Relay Protection introduces the power system protection, including basic fundamental understanding of relaying, common protection methods and relay applications. The first part of the course reviews the technical tools of the relay engineering (phasors, polarity and symmetrical components), fault analyzes, protection fundamentals and basic design principles. The second part of the course focuses on the line, transformer, bus, generation and motor protection. The course will be accompanied by relay protection laboratory where students will have hands on experience with main types of protective relays. Offered as ECSE 379 and ECSE 479. Prereq: Graduate student standing.

ECSE 480A. Introduction to Wireless Health. 3 Units.
Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as ECSE 480A and EBME 480A.
ECSE 480B. The Human Body. 3 Units.
Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as ECSE 480B and EBME 480B.

ECSE 480C. Biomedical Sensing Instrumentation. 3 Units.
Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as ECSE 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

ECSE 480D. The Health Care Delivery Ecosystem. 3 Units.
Health care delivery across the continuum of care in the United States, including health policy and reform, financing of care, comparative health systems, population health, public health, access to care, care models, cost and value, comparative effectiveness, governance, management, accountability, workforce, and the future. Discussions of opportunities and challenges for wireless health, integrated into the foregoing topics. Perspective on health care delivery in other countries. Offered as ECSE 480D and EBME 480D.

ECSE 480E. Wireless Communications and Networking. 3 Units.
Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as ECSE 480E and EBME 480E.

ECSE 480F. Physicians, Hospitals and Clinics. 3 Units.
Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as ECSE 480F and EBME 480F.

ECSE 480G. Applied Cryptography. 3 Units.
This course begins with a discussion of how mobility-driven computing and communication systems use cryptography to protect data and protocols. The foundation for critical cryptographic concepts, techniques, and algorithms are covered. The fundamental cryptographic concepts are studied, including: symmetric encryption, public key encryption, digital signatures, cryptographic hash function, and message authentication codes; cryptographic protocols, such as key exchange, remote user authentication, and interactive proofs; cryptanalysis of cryptographic primitives and protocols, such as by side-channel attacks, differential cryptanalysis, or replay attacks; and cryptanalytic techniques on deployed systems, such as memory remanence, timing attacks, fault attacks, and differential power analysis. Techniques used for code making (cryptographic) and break codes (cryptanalytic) are covered, as well as how these techniques are used within larger security systems.

ECSE 480H. Software Security. 3 Units.
This course begins with discussions of good software engineering practices to ensure security in modern software systems and additional challenges to security due to code mobility in software for mobility-driven computing. The basics of software security and threat models, methods to protect software (operating systems, databases, distributed software) - including risk analysis, authentication and authorization, access control, and software architecture for security - are studied. Principles of secure coding, validation and verification of secure software, software and data watermarking, code obfuscation, tamper resistant software are studied, as well as the benefits of open source and closed source software. Use of software as an attack mechanism and emerging attack models (including joint hardware-software attacks) are studied.

ECSE 480K. Hardware Security. 3 Units.
This course begins with the keys to enabling secure, trustworthy operation of computer hardware - understanding security issues and how appropriate security measures are included during design, verification, test, and deployment. Increasingly the security primitives such as the Trusted Computing Module are being introduced at the hardware level to prevent the compromise of security in systems being deployed today. A comprehensive coverage of security issues in computer hardware is provided. Topics of embedded systems security, hardware Trojans, security in implantable medical devices, security in RFID/NFC, protection from side channel attacks, tamper resistance and crypto processor design, trusted FPGA design/JTAG, hardware-based cryptanalysis, and hardware IP protection against piracy and reverse-engineering are covered. A course project (Can you Hack It?) that challenges students to hack a hardware is included.

ECSE 480Q. Regulatory Policy and Regulations. 3 Units.
Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the House of Representatives and its committees; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/ FDA MoU; CMS and Reimbursement; privacy and security. Offered as ECSE 480Q and EBME 480Q.

ECSE 480R. User Experience Engineering. 3 Units.
Social, cognitive, behavioral, and contextual elements in the design of healthcare technology and systems. User-centered design paradigm from a broad perspective, exploring dimensions of product user experience and learning to assess and modify the design of healthcare technology. Practical utilization of user centered design method and assessment techniques for approaching a design problem. Offered as ECSE 480R and EBME 480R.

ECSE 480S. Wireless Health Product Development. 3 Units.
Integrating application requirements, market data, concept formulation, design innovation, and manufacturing resources for creating differentiated wireless health products that delight the user. Learning user-centric product development best practices, safety, security and privacy considerations, and risk management planning. Understanding the regulatory process. Identifying and managing product development tradeoffs. Offered as ECSE 480S and EBME 480S. Prereq: EECS 480R.
ECSE 480T. Wearable Computing Design. 3 Units.
Learning about wearable devices using flexible/conformal electronics designed for convenience and uninterrupted wear-ability. Examining related design challenges from the technology, human and business points of view. Understanding wearable product design for general and special-purpose tasks in information processing, media operations, and information extraction from sensed data. Learning about the technological challenges for design, including miniaturization, power delivery and management, data storage, and wireless networking. Learning about hardware choices (processor, field programmable gate array or custom ASIC based design) for wearable computers and software architectures for smart data processing. Learning about wearable designs centered on the human experience, including sensing and interfacing with the human body, as well as user interaction, convenience, and support for non-intrusive social appearance. Case studies tying the business requirements with the technology and design issues.

ECSE 480U. Wearable Computing Technology. 3 Units.
Learning about a broad range of cutting-edge technologies suitable for wearable computing. Understanding printed and flexible electronics technologies required for creating wearable computing, in particular organsics for active components due to their flexibility or conformity. Examine the tradeoffs between flexible/conformal versus rigid electronics in the context of wearable computing. Reviewing the history of printed electronics used as conductors for membrane keypads, car windscreen heaters and RFID tag antennas-to name a few application examples. Reviewing the latest technology advances in functional components such as displays, lighting, transistors (p-type & n-type), memory, batteries, photovoltaics (PV), sensors, and conductors as well as integration/packaging steps. Understanding the market potential of these technologies by reviewing emerging products.

ECSE 480W. Wearable Computing Manufacturing. 3 Units.
Learning about the supply chain and manufacturing processes for flexible electronics, sensors, and other technologies contributing to the development of wearable products. Understanding supply chain issues in low mobility materials, multilevel substrates, nanocomposites, materials for low power sensors, and inks suitable for direct printing. Identifying the tradeoffs involved in various manufacturing methods such as roll-to-roll manufacturing a mature coating technology yet to be proven for full device integration. Studying other manufacturing techniques such as plate-to-plate, direct printing, 3D printing, and screening techniques for their applicability to the manufacturing and integration of flexible electronics. Understanding the use of lithography and vapor deposition techniques in the context of flexible electronics. Examining the issues of systems integration and packaging of the manufactured products.

ECSE 480X. Mobility-Driven Computing. 3 Units.
Fundamental concepts in computing and architecture for mobile devices, mobile operating systems, mobility and mobile data management. Application of technologies for location awareness, context awareness, integrated sensors, mobile Internet, displays, pattern recognition and natural language processing, and touch/gesture based user interaction. Understanding of the tradeoffs in design (smartphones, tablets) due to resource constraints such as wireless connectivity, application processing, power management, and graphics. Integration of near- and wide-area wireless communication technologies (Bluetooth, Wireless WAN). Exploration of emerging technologies and services for the mobile platform. Integration of the foregoing concepts in a specific mobile context application (home/office, pedestrian, vehicular).

ECSE 480Y. Mobility-Driven Embedded Systems. 3 Units.
Foundations of reliable, energy-efficient and secure design of embedded systems. Fundamentals of mobility in embedded systems including wireless technology, location awareness, sensors, and actuators. Design consideration for processors, DSP memory, and interfaces under mobility constraints (connectivity, power, and data management). Systems software for embedded computing, device management, and real-time I/O. Software design under constraints of size, performance, availability, and reliability. Software development techniques and practices (compilers, OS, and runtime systems). Case studies of mobility driven real-time embedded systems. Applications of mobility driven embedded systems, for example in in biomedical implant systems.

ECSE 480Z. Mobile Applications Development. 3 Units.
Understanding of the mobile application architecture, operating systems, and platforms. Challenges and opportunities in mobile application development. Evaluation of the leading mobile platform frameworks with respect to their features, functions, libraries, support, and ease of development. Software design for mobile applications in gaming, multimedia, entertainment, and enterprise applications. Development of enhanced user experience in a multi-touch, multi-sensor (accelerometer, gyroscopes, camera, geo-location) environment. Understanding of software development environments and testing tools, and use of wireless connectivity and data in mobile applications. Development of or extension of a modest application based on a major mobile platforms (iOS, Windows Phone 7, or Android).

ECSE 484. Computational Intelligence I: Basic Principles. 3 Units.
This course is concerned with learning the fundamentals of a number of computational methodologies which are used in adaptive parallel distributed information processing. Such methodologies include neural net computing, evolutionary programming, genetic algorithms, fuzzy set theory, and "artificial life." These computational paradigms complement and supplement the traditional practices of pattern recognition and artificial intelligence. Functionalities covered include self-organization, learning a model or supervised learning, optimization, and memorization.

ECSE 485. VLSI Systems. 3 Units.
Basic MOSFET models, inverters, steering logic, the silicon gate, nMOS process, design rules, basic design structures (e.g., NAND and NOR gates, PLA, ROM, RAM), design methodology and tools (spice, N.mpc, Caesar, mkpla), VLSI technology and system architecture. Requires project and student presentation, laboratory.
ECSE 486. Quantum Computing, Information, and Devices. 3 Units.
An introduction to the math, physics, engineering, and computer science underlying the rapidly emerging fields of quantum computing, quantum information, and quantum devices. The course is taught by a group of faculty from physics, engineering, computer science, and mathematics, geared towards students with diverse backgrounds and interests in these fields. Students will select a concentration in one of these four areas, and the coursework, while still covering all topics, will be adjusted to focus on the selected area in the most detail. Note that the listed prerequisites depend on choice of concentration. Topics will include: 1. (Mathematics) Introduction to linear algebra, convex geometry, fundamental theory of quantum information. 2. (Physics) Introduction to the quantum mechanics of two-level systems (qubits). Survey of physics and materials for qubit technologies. 3. (Computer Science) Basic quantum gates and circuits, introduction to the theory of algorithms, survey of quantum algorithms. 4. (Engineering) Quantum architectures, mapping algorithms onto circuits. The course consists of lectures, homework, and group projects. Group projects will aim to synthesize the diverse backgrounds of the students and instructors to capture the interdisciplinary nature of the field. Students taking the course for graduate credit will complete an additional literature research project and presentation, in addition to enhanced problem sets. Offered as CSDS 386, CSDS 486, ECSE 386, ECSE 486, MATH 386, MATH 486, PHYS 386, and PHYS 486. Prereq: (CSDS 281 or ECSE 281) and (ENGR 131 or CSDS 132 or ECSE 132) and (MATH 223 or MATH 227) and (MATH 224 or MATH 228) and (PHYS 122 or PHYS 124).

ECSE 487. Advanced Game Development Project. 3 Units.
This game development project course will bring together an interprofessional group of students in the fields of engineering, computer science, and art to focus on the design and development of a complete, fully functioning computer game as an interdisciplinary team. The student teams are given complete liberty to design their own fully functional games from their original concept to a playable game published in an online marketplace. Students will experience the entire game development cycle as they execute their projects. Responsibilities include creating a game idea, writing a story, developing the artwork, designing characters, implementing music and sound effects, programming and testing the game, and publishing the final project. Students enrolled in 487 will develop a healthcare or education virtual environment or video game in collaboration with a mentor who has expertise in the chosen area. Offered as CSDS 390, ECSE 390, CSDS 487, and ECSE 487. Prereq: Graduate student standing.

ECSE 488. Embedded Systems Design. 3 Units.
Objective: to introduce and expose the student to methodologies for systematic design of embedded system. The topics include, but are not limited to, system specification, architecture modeling, component partitioning, estimation metrics, hardware software codesign, diagnostics.

ECSE 489. Robotics I. 3 Units.

ECSE 490. Digital Image Processing. 3 Units.
Digital images are introduced as two-dimensional sampled arrays of data. The course begins with one-to-one operations such as image addition and subtraction and image descriptors such as the histogram. Basic filters such as the gradient and Laplacian in the spatial domain are used to enhance images. The 2-D Fourier transform is introduced and frequency domain operations such as high and low-pass filtering are developed. It is shown how filtering techniques can be used to remove noise and other image degradation. The different methods of representing color images are described and fundamental concepts of color image transformations and color image processing are developed. One or more advanced topics such as wavelets, image compression, and pattern recognition will be covered as time permits. Programming assignments using software such as MATLAB will illustrate the application and implementation of digital image processing. Offered as CSDS 490 and ECSE 490.

ECSE 494. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended preparation: MATH 201 or MATH 307. Offered as MATH 394, CSDS 394, ECSE 394, MATH 494, CSDS 494 and ECSE 494.

ECSE 499. Algorithmic Robotics. 3 Units.
This course introduces basic algorithmic techniques in robotic perception and planning. Course is divided into two parts. The first part introduces probabilistic modeling of robotic motion and sensing, Gaussian and nonparametric filters, and algorithms for mobile robot localization. The second part introduces fundamental deterministic and randomized algorithms for motion planning. Offered as CSDS 499 and ECSE 499. Prereq: Graduate Standing or Requisites Not Met permission.

ECSE 500. ECSE Colloquium. 0 Unit.
Seminars on current topics in Electrical, Computer and Systems Engineering.

ECSE 500T. Graduate Teaching II. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, running recitation sessions, providing laboratory assistance. Recommended preparation: Ph.D. student in ECSE department.
ECSE 526. Integrated Mixed-Signal Systems. 3 Units.
Mixed-signal (analog/digital) integrated circuit design. D-to-A and A-to-D conversion, applications in mixed-signal VLSI, low-noise and low-power techniques, and communication sub-circuits. System simulation at the transistor and behavioral levels using SPICE. Class will design a mixed-signal CMOS IC for fabrication by MOSIS. Recommended preparation: EECS/ECSE 426.

ECSE 527. Advanced Sensors: Theory and Techniques. 3 Units.
Sensor technology with a primary focus on semiconductor-based devices. Physical principles of energy conversion devices (sensors) with a review of relevant fundamentals: elasticity theory, fluid mechanics, silicon fabrication and micromachining technology, semiconductor device physics. Classification and terminology of sensors, defining and measuring sensor characteristics and performance, effect of the environment on sensors, predicting and controlling sensor error. Mechanical, acoustic, magnetic, thermal, radiation, chemical and biological sensors will be examined. Sensor packaging and sensor interface circuitry.

ECSE 589. Robotics II. 3 Units.
Survey of research issues in robotics. Force control, visual servoing, robot autonomy, on-line planning, high-speed control, man/machine interfaces, robot learning, sensory processing for real-time control. Primarily a project-based lab course in which students design real-time software executing on multi-processors to control an industrial robot. Recommended preparation: EECS/CSDS/ECSE 489. Offered as CSDS 589 and ECSE 589.

ECSE 600. Special Topics. 1 - 18 Units.

ECSE 600T. Graduate Teaching III. 0 Unit.
This course will provide Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities running recitation sessions, providing laboratory assistance, developing teaching or lecture materials presenting lectures. Recommended preparation: Ph.D. student in ECSE department.

ECSE 601. Independent Study. 1 - 18 Units.

ECSE 620. Special Topics. 1 - 18 Units.

ECSE 621. Special Projects. 1 - 18 Units.

ECSE 651. Thesis M.S.. 1 - 18 Units.
Credit as arranged.

ECSE 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EECS Plan B MS Program.

ECSE 701. Dissertation Ph.D.. 1 - 9 Units.
Credit as arranged.