Electrical & Systems Engineering

The Department of Electrical & Systems Engineering offers doctoral-level and master's-level degrees in Electrical Engineering and in Systems Science & Mathematics. At the doctoral level, both the PhD and DSc degrees are available; these typically require four to five years of full-time study leading to an original research contribution. At the master's level, the programs require 30 credit units of study and have both a course option and a thesis option.

Research activity in the department is focused in the following four areas:

Applied Physics

- Nanophotonics
- Quantum optics
- Engineered materials
- Electrodynamics

Devices & Circuits

- Computer engineering
- Integrated circuits
- Radiofrequency circuits
- Sensors

Systems Science

- Optimization
- Applied mathematics
- Control
- Financial engineering

Signals & Imaging

- Computational imaging
- Signal processing
- Optical imaging
- Data sciences

Students working in any of these areas will enjoy the benefits of programs that balance fundamental theoretical concepts with modern applications. In our department, students find ample opportunities for close interactions with faculty members working on cutting-edge research and technology development.

Prospective PhD students with previous degrees in engineering who are interested in PhD studies and research in mathematics or statistics are encouraged to apply for PhD studies in Mathematics and Statistics. For more details, visit the Graduate Programs in Mathematics and Statistics webpage.

Phone:	314-935-5565
Website:	https://ese.wustl.edu/academics/graduate-programs/index.html

Faculty

Chair

Bruno Sinopoli
Das Family Distinguished Professor
PhD, University of California, Berkley
Designs safe and secure networked embedded control systems

Endowed Professors

Shantanu Chakrabartty
Clifford W. Murphy Professor
Vice Dean for Research and Graduate Education
PhD, Johns Hopkins University
Explores frontiers in analog and neuromorphic integrated circuits

Jr-Shin Li
Newton R. and Sarah Louisa Glasgow Wilson Professor of Engineering
PhD, Harvard University
Studies complex large-scale systems arising from emerging physical, biological and medical applications

Joseph A. O'Sullivan
Samuel C. Sachs Professor of Electrical Engineering
Dean, UMSL/WashU Joint Undergraduate Engineering Program
PhD, Notre Dame University
Discovers ways to improve CT imaging & optical imaging

Lan Yang
Edward H. & Florence G. Skinner Professor of Engineering
PhD, California Institute of Technology
Focuses on advanced nano/micro photonic devices with outstanding optical properties

Professor

ShiNung Ching
Associate Chair for Research
PhD, University of Michigan
Engineering Neuroscience, Dynamics, Control

Associate Professors

Xudong Chen
PhD, Harvard University
Develops revolutionary methods for analysis and control of large-scale multi-agent systems

Andrew Clark
PhD, University of Washington
Focused on control and security of networked and cyber-physical systems

Ulugbek Kamilov
PhD, École Polytechnique Fédérale de Lausanne, Switzerland
Advances imaging technology through research on computational imaging, computer vision, machine learning and optimization

Matthew Lew
Associate Chair for Academic Programs
PhD, Stanford University
Builds new nanoscale imaging technologies

Jung-Tsung Shen
PhD, Massachusetts Institute of Technology
Exploits the unique properties of quantum nano-photonics for applications in quantum communication, computation and biomedical imaging

Chuan Wang
Director of Graduate Programs
PhD, University of Southern California
Develops large-scale and cost-effective materials for flexible and stretchable electronic systems

Assistant Professors

Hong Hu
PhD, Harvard University
Developing theoretical foundations for high-dimensional information processing

Ioannis (Yiannis) Kantaros
PhD, Duke University
Designs safe and distributed autonomy algorithms for large-scale multi-robot systems

Mark Lawrence
PhD, University of Birmingham
Builds novel systems and devices for applications in telecommunications, computing and quantum information

Janet Sorrells
PhD, University of Illinois at Urbana-Champaign
Developing new technologies in label-free nonlinear optical microscopy to enable new applications in biology and medicine

Shen Zeng
PhD, University of Stuttgart
Develops data-integrated computational approaches for controlling complex dynamic systems

Senior Professors

Paul S. Min
PhD, University of Michigan
Routing and control of telecommunication networks, fault tolerance and reliability, software systems, network management

Robert E. Morley Jr.
DSc, Washington University in St. Louis
Computer engineering, lower-power VLSI design, computer architecture, signal processing, microprocessors systems design

Hiro Mukai
PhD, University of California, Berkeley
Theory and computational methods for optimization, optimal control, systems theory, electric power system operations, differential games

Daniel L. Rode
PhD, Case Western Reserve University
Optoelectronics and fiber optics, semiconductor materials, light-emitting diodes and lasers, semiconductor processing, electronics

Ervin Y. Rodin
PhD, University of Texas at Austin
Optimization, differential games, artificial intelligence, mathematical modeling

Heinz Schaettler
PhD, Rutgers University
Optimal control, nonlinear systems, mathematical models in biomedicine

Barbara A. Shrauner
PhD, Harvard University (Radcliffe)
Plasma processing, semiconductor transport, symmetries of nonlinear differential equations

Barry E. Spielman
PhD, Syracuse University
High-frequency/high-speed devices, radiofrequency and microwave integrated circuits, computational electromagnetics

Tzyh Jong Tarn
DSc, Washington University
Quantum mechanical systems, bilinear and nonlinear systems, robotics and automation, life science automation

Professors of Practice

Dennis Mell
MS, University of Missouri–Rolla
Focuses on cross-disciplinary applications of robotics and automation systems

Ed Richter
MS, Washington University
Designs and develops biomedical signal processing systems including analog instrumentation, digital circuits with microcontrollers and FPGAs, and application programming; teaches electrical and computer engineering lab courses in FPGA design and development and signal processing and communications

Jason Trobaugh
DSc, Washington University
Ultrasound imaging, diffuse optical tomography, image-guided therapy, ultrasonic temperature imaging

Teaching Professor

James Feher
PhD, Missouri University of Science and Technology
Interested in the use and implementation of open source hardware and software as it is applied to engineering education

Vladimir Kurenok
PhD, Belarus State University (Minsk, Belarus)
Focuses on studying and applications of random models under low regularity assumptions

Senior Lecturers

Martha Hasting
PhD, Saint Louis University
Mathematics education

Tsitsi Madziwa-Nussinov
PhD, University of California, Los Angeles
Teaches Introduction to Electrical and Electronic Circuits

Dorothy Wang
PhD, Virginia Tech
Fiber optic sensing, electro-optical sensors

Jinsong Zhang
PhD, University of Miami
Focused on signal, data and information processing with applications to engineering systems

Lecturers

Michael Hall
PhD, Washington University in St Louis
Teaches computer engineering, preparing students with essential skills and knowledge to achieve their professional goals and contribute to technological advancements that benefit society

Ben Wormleighton
PhD, University of California, Berkeley
Seeks to cultivate formative learning spaces and practices that develop creative and communal thinkers

Professors Emeriti

R. Martin Arthur
Newton R. and Sarah Louisa Glasgow Wilson Professor of Engineering
PhD, University of Pennsylvania
Ultrasonic imaging, electrocardiography

Arye Nehorai
The Eugene & Martha Lohman Emeritus Professor of Electrical Engineering
PhD, Stanford University
Statistical signal processing, machine learning, imaging, biomedicine

Degree Requirements

The Department of Electrical & Systems Engineering offers doctoral-level and master's-level degrees in Electrical Engineering and in Systems Science & Mathematics as well as a certificate in Imaging Science. At the doctoral level, both the PhD and DSc degrees are available; these typically require four to five years of full-time study leading to an original research contribution. At the master's level, the programs require a minimum of 30 units of study consistent with the residency and other applicable requirements of Washington University and McKelvey School of Engineering. The master's degrees may be pursued with a course-only option or a thesis option.

Students will enjoy the benefits of programs that balance fundamental theoretical concepts with modern applications. In our department, students will find ample opportunities for close interactions with faculty members working on cutting-edge research and technology development.

Please visit the following pages for more information about our programs:

- Electrical Engineering, PhD
- Systems Science & Mathematics, PhD
- Electrical Engineering, DSc
- Systems Science & Mathematics, DSc
- Electrical Engineering, MSEE
- Systems Science & Mathematics, MSSSM
- Engineering Data Analytics & Statistics, MSDAS
- Computer Engineering, MS
- Controls Certificate
- Financial Engineering Certificate
- Imaging Science & Engineering Certificate
- Quantum Engineering Certificate

Courses

ESE 5000 Research Rotation for ESE Masters Students
Masters students in Electrical and Systems Engineering may complete a rotation their first semester with research mentors acceptable to the Department. The rotations must be mutually agreeable to both the student and faculty member. The grade will be assigned based on a written report from the rotation. The rotation allows students to sample different research projects and laboratory working environments, to enable matching masters students and research mentors with whom they will carry out thesis research.
Credit 3 units.
Typical periods offered: Fall

ESE 5010 Mathematics of Modern Engineering I
Matrix algebra: systems of linear equations, vector spaces, linear independence and orthogonality in vector spaces, eigenvectors and eigenvalues; Vector calculus: gradient, divergence, curl, line and surface integrals, theorems of Green, Stokes, and Gauss; Elements of Fourier analysis and its applications to solving some classical partial differential equations, heat, wave, and Laplace equation.
Credit 3 units.
Typical periods offered: Fall, Summer

ESE 5020 Mathematics of Modern Engineering II
This course covers Fourier series and Fourier integral transforms and their applications to solving some partial differential equations and heat and wave equations. It also presents complex analysis and its applications to solving real-valued problems, including analytic functions and their role, Laurent series representation, complex-valued line integrals and their evaluation (including the residual integration theory), and conformal mappings and their applications.
Credit 3 units.
Typical periods offered: Spring, Summer

ESE 5130 Large-Scale Optimization for Data Science
Large-scale optimization is an essential component of modern data science, artificial intelligence, and machine learning. This graduate-level course rigorously introduces optimization methods that are suitable for large-scale problems arising in these areas. Students will learn several algorithms suitable for both smooth and nonsmooth optimization, including gradient methods, proximal methods, mirror descent, Nesterov's acceleration, ADMM, quasi-Newton methods, stochastic optimization, variance reduction, and distributed optimization. Throughout the course, we will discuss the efficacy of these methods in concrete data science problems, under appropriate statistical models. Students will be required to program in Python or MATLAB.
Credit 3 units.
Typical periods offered: Fall

ESE 5200 Probability and Stochastic Processes
This course covers a review of probability theory; models for random signals and noise; calculus of random processes; noise in linear and nonlinear systems; representation of random signals by sampling and orthonormal expansions; and Poisson, Gaussian, and Markov processes as models for engineering problems.
Credit 3 units.
Typical periods offered: Fall, Spring

ESE 5230 Information Theory
Discrete source and channel model, definition of information rate and channel capacity, coding theorems for sources and channels, encoding and decoding of data for transmission over noisy channels.
Credit 3 units.
Typical periods offered: Fall

ESE 5240 Detection and Estimation Theory
Study of detection and estimation of signals in noise. Linear algebra, vector spaces, independence, projections. Data independence, factorization theorem and sufficient statistics. Neyman-Pearson and Bayes detection. Least squares, maximum-likelihood and maximum a posteriori estimation of signal parameters. Conjugate priors, recursive estimation, Wiener and Kalman filters.
Credit 3 units.
Typical periods offered: Spring

ESE 5310 Nano and Micro Photonics
This course focuses on fundamental theory, design, and applications of photonic materials and micro/nano photonic devices. It includes review and discussion of light-matter interactions in nano and micro scales, propagation of light in waveguides, nonlinear optical effect and optical properties of nano/micro structures, the device principles of waveguides, filters, photodetectors, modulators and lasers.
Credit 3 units.
Typical periods offered: Spring

ESE 5320 Introduction to Nano-Photonic Devices
Introduction to photon transport in nano-photonic devices. This course focuses on the following topics: light and photons, statistical properties of photon sources, temporal and spatial correlations, light-matter interactions, optical nonlinearity, atoms and quantum dots, single- and two-photon devices, optical devices, and applications of nano-photonic devices in quantum and classical computing and communication.
Credit 3 units.
Typical periods offered: Fall

ESE 5330 Nanophotonic Optical Media - From Metamaterials to Photonic Crystals and Beyond
The nanometer length scale holds a unique significance for optical engineering because it is home to the wavelengths of visible and infrared light. The behavior of a light wave is particularly sensitive to structural features formed at or below the scale of its wavelength and, as a consequence, nanophotonics encompasses many new and useful phenomena not found in macroscopic systems. In this course, we will explore the physics of light-matter coupling before using it as a guide to engineer new optical material properties via nanofabrication, with applications in computing, telecommunications, biomedical sensing, solar energy harvesting, robotics and more. Key topics covered in the course include Mie resonant dielectric antennas, plasmonic antennas, negative and zero refractive index metamaterials, chiral metamaterials, metasurface lenses and holograms, nonlinear and time dependent metasurfaces, Bragg mirrors, 3D photonic crystals, photonic crystal slab waveguides and cavities, guided mode resonators, photonic crystal lasers.
Credit 3 units.
Typical periods offered: Spring

ESE 5332 Hardware & Devices: RF and Microwave Component and System Design
The course aims at provide understanding of the passive and active design for modern-day RF and microwave wireless systems. The lecture-based learning in the course will be coupled with simulation in professional circuit simulators including ADS and Cadence Virtuoso, and literature review of recent advances in RFIC design. Topics in Passive Design Include Transmission Line Theory, S-parameters, Smith Chart for matching network design, Inductors, Capacitors, Power Dividers, Directional Couplers, Isolators, and Circulators. Topics in Active Design include RF transistor modelling, Power Gain, Stability, Noise, Non-linearity, Low Noise Amplifiers, Mixers, small signal amplifiers, and Oscillators. Topics in System Design include Modern Receiver architectures and design considerations, course project.
Credit 3 units.
Typical periods offered: Spring

ESE 5360 Introduction to Quantum Optics
This course covers the following topics: quantum mechanics for quantum optics, radiative transitions in atoms, lasers, photon statistics (photon counting, Sub-/Super-Poissionian photon statistics, bunching, anti-bunching, theory of photodetection, shot noise), entanglement, squeezed light, atom-photon interactions, cold atoms, atoms in cavities. If time permits, the following topics will be selectively covered: quantum computing, quantum cryptography, and teleportation.
Credit 3 units.
Typical periods offered: Fall

ESE 5430 Control Systems Design By State Space Methods
Advanced design and analysis of control systems by state-space methods: classical control review, Laplace transforms, review of linear algebra (vector space, change of basis, diagonal and Jordan forms), linear dynamic systems (modes, stability, controllability, state feedback, observability, observers, canonical forms, output feedback, separation principle and decoupling), nonlinear dynamic systems (stability, Lyapunov methods). Frequency domain analysis of multivariable control systems. State space control system design methods: state feedback, observer feedback, pole placement, linear optimal control. Design exercises with CAD (computer-aided design) packages for engineering problems.
Credit 3 units.
Typical periods offered: Fall

ESE 5440 Optimization and Optimal Control
Constrained and unconstrained optimization theory. Continuous time as well as discrete-time optimal control theory. Time-optimal control, bang-bang controls and the structure of the reachable set for linear problems. Dynamic programming, the Pontryagin maximum principle, the Hamiltonian-Jacobi-Bellman equation and the Riccati partial differential equation. Existence of classical and viscosity solutions. Application to time optimal control, regulator problems, calculus of variations, optimal filtering and specific problems of engineering interest.
Credit 3 units.
Typical periods offered: Spring

ESE 5450 Stochastic Control
Introduction to the theory of stochastic differential equations based on Wiener processes and Poisson counters, and an introduction to random fields. The formulation and solution of problems in nonlinear estimation theory. The Kalman-Bucy filter and nonlinear analogues. Identification theory. Adaptive systems. Applications. Prerequisites: ESE 520 and ESE 551
Credit 3 units.
Typical periods offered: Fall

ESE 5460 Dynamics & Control in Neuroscience & Brain Medicine
This course provides an introduction to systems engineering approaches to modeling, analysis and control of neuronal dynamics at multiple scales. A central motivation is the manipulation of neuronal activity for both scientific and medical applications using emerging neurotechnology and pharmacology. Emphasis is placed on dynamical systems and control theory, including bifurcation and stability analysis of single neuron models and population mean-field models. Synchronization properties of neuronal networks are covered and methods for control of neuronal activity in both oscillatory and non-oscillatory dynamical regimes are developed. Statistical models for neuronal activity are also discussed. An overview of signal processing and data analysis methods for neuronal recording modalities is provided, toward the development of closed-loop neuronal control paradigms. The final evaluation is based on a project or research survey.
Credit 3 units.
Typical periods offered: Fall

ESE 5470 Robust and Adaptive Control
Graduate-level control system design methods for multi-input multi-output systems. Linear optimal based methods in robust control, nonlinear model reference adaptive control. These design methods are currently used in most industry control system design problems. These methods will be designed, analyzed, and simulated using Matlab. Linear Control Theory (review), Robustness Theory (Mu Analysis), Optimal Control and the Robust Servomechanism, H-infinity Optimal Control, Robust Output Feedback Controls, Kalman Filter Theory and Design, Linear Quadratic Gaussian with Loop Transfer Recovery, The Loop Transfer Recovery Method of Lavretsky, Mu Synthesis, Lyapunov Theory (review), LaSalle extensions, Barbalat's Lemma, Model Reference Adaptive Control, Artificial Neural Networks, On-line parameter estimation, convergence, and Persistence of Excitation.
Credit 3 units.
Typical periods offered: Spring

ESE 5510 Linear Dynamic Systems I
Input-output and state-space description of linear dynamic systems. Solution of the state equations and the transition matrix. Controllability, observability, realizations, pole-assignment, observers and decoupling of linear dynamic systems.
Credit 3 units.
Typical periods offered: Fall

ESE 5530 Nonlinear Dynamic Systems
State space and functional analysis approaches to nonlinear systems. Questions of existence, uniqueness, and stability; Lyapunov and frequency-domain criteria; w-limits and invariance, center manifold theory and applications to stability, steady state response and singular perturbations. Poincare-Bendixson theory, the van der Pol oscillator and the Hopf Bifurcation theorem.
Credit 3 units.
Typical periods offered: Spring

ESE 5582 Data-Driven Control Methods and Reinforcement Learning
Modeling and control approaches of the past decades are usually concerned with analytically described control systems with relatively mild complexity, which allows for a highly successful treatment by rigorous systems theoretic methods. Recent years, however, have witnessed a significant shift towards the consideration of far more complicated control systems in which purely analytical approaches are infeasible. This is a research-focused course that will introduce and explore systematic approaches towards augmenting the core foundations of systems and control theoretic frameworks with data-integrating and learning-based capabilities to efficiently harness the vast amounts of valuable operational data and computing resources in order to solve challenging control tasks that escape the traditional setting. The starting point for these new developments are specific macroscopic considerations of dynamical systems associated with transfer operators and Koopman operators. After reviewing these operator-theoretic frameworks, we will explore a family of sample-based approaches that emerge out of the macroscopic viewpoint. These sample-based approaches not only mitigate drawbacks of the original operator-theoretic approaches but also facilitate more direct and efficient data-integrated paths for elucidating important features of dynamical systems with applications to control and estimation. Moreover, connections with established methods from Reinforcement Learning will be integrated into the course material.
Credit 3 units.
Typical periods offered: Spring

ESE 5592 Data-Driven Control Methods and Reinforcement Learning
Modeling and control approaches of the past decades are usually concerned with analytically described control systems with relatively mild complexity, which allows for a highly successful treatment by rigorous systems theoretic methods. Recent years, however, have witnessed a significant shift towards the consideration of far more complicated control systems in which purely analytical approaches are infeasible. This is a research-focused course that will introduce and explore systematic approaches towards augmenting the core foundations of systems and control theoretic frameworks with data-integrating and learning-based capabilities to efficiently harness the vast amounts of valuable operational data and computing resources in order to solve challenging control tasks that escape the traditional setting. The starting point for these new developments are specific macroscopic considerations of dynamical systems associated with transfer operators and Koopman operators. After reviewing these operator-theoretic frameworks, we will explore a family of sample-based approaches that emerge out of the macroscopic viewpoint. These sample-based approaches not only mitigate drawbacks of the original operator-theoretic approaches but also facilitate more direct and efficient data-integrated paths for elucidating important features of dynamical systems with applications to control and estimation.

Moreover, connections with established methods from Reinforcement Learning will be integrated into the course material. Prereqs: ESE 415 Optimization, ESE 551 Linear Dynamic Systems, ESE 553 Nonlinear Dynamic Systems
Credit 3 units.

Typical periods offered: Spring

ESE 5620 Analog Integrated Circuits
This course focuses on fundamental and advanced topics in analog and mixed-signal VLSI techniques. The first part of the course covers graduate level materials in the area of analog circuit synthesis and analysis. The second part of the course covers applications of the fundamental techniques for designing analog signal processors and data converters. Several practical aspects of mixed-signal design, simulation and testing are covered in this course. This is a project-oriented course and it is expected that the students apply the concepts learned in the course to design, simulate and explore different circuit topologies.
Credit 3 units.

Typical periods offered: Fall

ESE 5660 Modern System-On-Chip Design
The System-on-Chip (SoC) technology is at the core of most electronic systems: smartphones, wearable devices, autonomous robots and cars, and aerospace and medical electronics. In these SoCs, billions of transistors can be integrated on a single silicon chip containing various components, such as microprocessors, DSPs, hardware accelerators, memories, and I/O interfaces. Topics include SoC architectures, design tools, and methods as well as system-level trade-offs between performance, power consumption, energy efficiency, reliability, and programmability. Students will gain an insight into the early stages of the SoC design process by performing the tasks of developing functional specifications, applying partitions and map functions to hardware and/or software, and then evaluating and validating system performance. Assignments include hands-on design projects. This course is open to both graduate and senior undergraduate students.
Credit 3 units.

Typical periods offered: Fall, Spring

ESE 5700 Coding Theory
Introduction to the algebra of finite fields. Linear block-codes, cyclic codes, BCH and related codes for error detection and correction. Encoder and decoder circuits and algorithms. Spectral descriptions of codes and decoding algorithms. Code performances.
Credit 3 units.

ESE 5820 Fundamentals and Applications of Modern Optical Imaging
Analysis, design, and application of modern optical imaging systems with emphasis on biological imaging. First part of course will focus on the physical principles underlying the operation of imaging systems and their mathematical models. Topics include ray optics (speed of light, refractive index, laws of reflection and refraction, plane surfaces, mirrors, lenses, aberrations), wave optics (amplitude and intensity, frequency and wavelength, superposition and interference, interferometry), Fourier optics (space-invariant linear systems, Huygens-Fresnel principle, angular spectrum, Fresnel diffraction, Fraunhofer diffraction, frequency analysis of imaging systems), and light-matter interaction (absorption, scattering, dispersion, fluorescence). Second part of course will compare modern quantitative imaging technologies including, but not limited to, digital holography, computational imaging, and super-resolution microscopy. Students will evaluate and critique recent optical imaging literature.
Credit 3 units.

Typical periods offered: Spring

ESE 5830 Nonlinear Optical Microscopy
This course will cover the theoretical and practical knowledge needed to design, construct, and use a nonlinear optical microscope. The course will focus on the relevant optical physics and instrumentation for different types of nonlinear optical microscopy, and additionally provide some information on applications and image processing. Topics include: ultrafast lasers, detectors, nonlinear susceptibility, nonlinear wave equation, quantum theory of nonlinear optics, harmonic generation, multiphoton fluorescence, fluorescence lifetime, optical metabolic imaging, coherent Raman scattering, and multimodal nonlinear optical microscopy.
Credit 3 units.

Typical periods offered: Fall

ESE 5860 Tomographic Systems
The study of systems for imaging the interior of an object from external measurements. Mathematical preliminaries: multidimensional linear-systems, the Poisson process, maximum-likelihood estimation. Transmission, emission, reflection, and magnetic-resonance tomography. Line integral, strip integral, weighted-integral, and divergent-ray descriptions of tomographic data. The Radon transform. Reconstruction from ideal data: filtered back-project, back-project filter, Fourier, and inverse Radon-transform methods. Reconstruction from ideal data: filtered back-project, back-project filter, Fourier, and inverse Radon-transform methods. Reconstruction from blurred and noisy data: confidence-weighting, minimum-divergence deblurring, and estimation-based methods. Techniques for treatment of mission data, attenuation, and accidentals. Application to positron-emission, single-photon emission, x-ray, and magnetic-resonance tomography and to high resolution radar-imaging. Computer architectures for producing tomographic imagery.
Credit 3 units.

Typical periods offered: Fall

ESE 5890 Biological Imaging Technology
This class will develop a fundamental understanding of the physics and mathematical methods that underlie biological imaging and critically examine case studies of seminal biological imaging technology literature. The physics section will examine how electromagnetic and acoustic waves interact with tissues and cells, how waves can be used to image the biological structure and function, image formation methods and diffraction limited imaging. The math section will examine image decomposition using basis functions (e.g. Fourier transforms), synthesis of measurement data, image analysis for feature extraction, reduction of multi-dimensional imaging datasets, multivariate regression, and statistical image analysis. Original literature on electron, confocal and two photon microscopy, ultrasound, computed tomography, functional and structural magnetic resonance imaging and other emerging imaging technology will be critiqued.
Credit 3 units.

Typical periods offered: Spring

ESE 5932 Computational Methods for Imaging Science
Inverse problems are ubiquitous in science and engineering, and they form the basis for modern imaging methods. This course will introduce students to the mathematical formulation of inverse problems and modern computational methods employed to solve them. Specific topics covered will include regularization theory, compressive sampling, variational calculus, and a survey of relevant numerical optimization methods. The application of these methods to tomographic imaging problems will be addressed in detail.
Credit 3 units.

Typical periods offered: Spring

ESE 5933 Theoretical Imaging Science
Imaging science encompasses the design and optimization of imaging systems to quantitatively measure information of interest. Imaging systems are important in many scientific and medical applications and may be designed for one specific application or for a range of applications. Performance is quantified for any given task through an understanding of the statistical model for the imaging data, the data processing algorithm used, and a measure of accuracy or error. Optimal processing is based on statistical decision theory and estimation theory; performance bounds include the receiver operating characteristic and Cramer-Rao bounds. Bayesian methods often lead to ideal observers. Extensions of methods from finite-dimensional spaces to function space are fundamental for many imaging applications. A variety of methods to assess image quality and resulting imaging system optimization are covered.
Credit 3 units.
Typical periods offered: Fall

ESE 5970 Practicum in Imaging Science
Students develop research results in computational imaging and write a conference paper on the results. This course involves the process of research project design and implementation in imaging science, participation in research teams, the development of milestones for a project, and the process of meeting expectations. The role of machine learning, computational methods, theoretical methods, datasets, and experiments in imaging science research are covered.
Credit 3 units.
Typical periods offered: Spring

ESE 5971 Practicum in Data Analytics & Statistics
In this course, students will learn through hands-on experience the application of analytics to support data-driven decisions. Through lectures and the execution of a project (to be defined at the beginning of the semester), students will learn to use descriptive, predictive, and prescriptive analytics. Lectures will focus on presenting analytic topics relevant to the execution of the project, including analytic model development, data quality and data models, review of machine learning algorithms (unsupervised, supervised, and semi-supervised approaches), model validation, insights generation and results communication, and code review and code repository. Students are expected to demonstrate the application of these concepts through the execution of a one-semester project. Students can propose their own projects or choose from a list of projects made available by the lecturer. Projects should reflect real-world problems with a clear value proposition. Progress will be evaluated and graded periodically during the semester, and the course will include a final presentation open to the academic community.
Credit 3 units.
Typical periods offered: Fall, Spring

ESE 5972 Practicum in Imaging Science and Engineering
This course provides students in the Imaging Science and Engineering program with opportunities to participate, early in their graduate studies, in projects involving image data. A list of IS&E faculty having potential projects of interest is provided. It is the student's responsibility to interview with such faculty in order to identify a project for themselves to be completed in one semester. A written report documenting the project goals, relevant literature, and results obtained is required at the end of the project. To receive credit for completing the practicum, the report must be accepted by the supervisor of the project and a committee of IS&E faculty. This course is graded Pass/Fail.
Credit 1 unit.
Typical periods offered: Fall, Spring

ESE 5980 Electrical & Systems Engineering Graduate Seminar
This satisfactory/unsatisfactory course is required for the master's, DSc, and PhD degrees in Electrical & Systems Engineering. A satisfactory grade is required for each semester of enrollment, and this is achieved by student attendance at regularly scheduled seminars. Master's students must attend at least three seminars per semester, except for first-year master's students, who must attend four. DSc and PhD students must attend at least five seminars per semester, except for first-year PhD students who must attend six. Part-time students are exempt except during their year of residency. Any student under continuing status is also exempt.
Credit 0 units.
Typical periods offered: Fall, Spring

ESE 5981 Seminar in Imaging Science and Engineering
This seminar course consists of a series of tutorial lectures on Imaging Science and Engineering with emphasis on applications of imaging technology. Students are exposed to a variety of imaging applications that vary depending on the semester, but may include multispectral remote sensing, astronomical imaging, microscopic imaging, ultrasound imaging, and tomographic imaging. Guest lecturers come from several parts of the university. This course is required of all students in the Imaging Science and Engineering program; the only requirement is attendance. This course is graded Pass/Fail.
Credit 1 unit.
Typical periods offered: Fall

ESE 5999 Independent Study
Opportunities to acquire experience outside the classroom setting and to work closely with individual members of the faculty. A final report must be submitted to the department. Students must have the ESE Research/Independent Study Registration Form approved by the department.
Credit 3 units.
Typical periods offered: Fall, Spring, Summer

ESE 7970 Masters Project
Students electing the project option for their master's degree perform their project work under this course. Consult the Masters student handbook for the requirements to successfully complete this degree option. Students must complete the ESE Project Registration Form to enroll in this course. The form requires an abstract of the work expected.
Credit 1-3 units.
Typical periods offered: Fall, Spring

ESE 7998 Masters Research
Students electing the thesis option for their master's degree perform their research under this course. Consult the Masters student handbook for the requirements to successfully complete this degree option. Students must complete the ESE Thesis Registration Form to enroll in this course. The form requires an abstract of the work expected.
Credit 3 units.
Typical periods offered: Fall, Spring, Summer

ESE 8991 Research Rotation for ESE Doctoral Students
Doctoral students in Electrical and Systems Engineering are required to complete two rotations during their first year and may complete three rotations, with research mentors acceptable to the separtment. The rotations must be mutually agreeable to both the student and the faculty member. The grade will be assigned based on a written

report from one of the rotations. The rotations allow students to sample different research projects and laboratory working environments and to enable the matching of doctoral students with the research mentors with whom they will carry out PhD dissertation research.

Credit 3 units.

Typical periods offered: Fall, Spring

ESE 8998 Doctoral Research

This course is designed for doctoral candidates to conduct advanced, original research in their field of study, leading to the completion of their dissertation. Students will engage in in-depth literature reviews, formulate research questions, develop and implement research methodologies, collect and analyze data, and write their dissertation under the guidance of their faculty advisor and dissertation committee. The course emphasizes critical thinking, scholarly integrity, and the advancement of knowledge. Regular meetings with the advisor and periodic progress reports are required. Successful completion is necessary for the awarding of the doctoral degree.

Credit 9 units.

Typical periods offered: Fall, Spring
