ELECTRICAL AND COMPUTER ENGINEERING 2013-2014

Why study engineering at the University of Denver?

DU's Department of Electrical and Computer Engineering (ECE) is creating the future of technology by providing a graduate education that emphasizes both multi-disciplinary and cross-disciplinary knowledge. The distinguished faculty is creating multi-disciplinary education and research programs that anticipate technological trends in research and development, as well as industry. Graduate students join the faculty in conducting leading-edge basic and applied research in emerging disciplines developing novel and unique solutions to old and new problems and opportunities.

All laboratories in the Department contain state-of-the-art equipment and software to support basic and applied research in hardware and software design, hardware/software interfacing, communications and signal processing, image processing, computer vision and pattern recognition, optoelectronics, power and energy systems, robotics, mechatronic systems, unmanned systems, among other research areas. Small classes support our multi-disciplinary and real-time focus by providing close contact between students and faculty, which allows us to meet students' individual career goals.

Denver is a first-rate location for business, government and laboratory partnerships, and technology employment. The Colorado Front Range is consistently rated as one of the top high-tech areas in the country, and DU is located just minutes from the Denver Technological Center, the site of many top technology companies. The Department of Electrical and Computer Engineering is committed to active collaboration with these industry leaders. As a result, our students graduate with relevant research experience and a network of employment contacts in the technology sector that is second to none!

The ECE Department offers, among other degrees, a Masters and a PhD degree in Mechatronic Systems Engineering (MSE). DU/ECE is the only University in the United States that offers BS, MS and PhD degrees in MSE.

Scholarships and Financial Aid

As a University of Denver graduate student, you may be eligible for financial aid. Need-based is available to U.S. citizens and permanent residents through loans. The Department of ECE also offers a number of Graduate Teaching Assistantships (GTAs) that provide full tuition remission along with a stipend for the nine-month academic year (three academic quarters) and Graduate Research Assistantships (GRAs) with or without partial tuition remission. These assistantships are open to both domestic and international students. Other sources of financial aid available to both domestic and international students include scholarships (outside of the University of Denver), fellowships, and work-study (available to U.S. citizens and permanent residents). For more information about financial aid, please contact the Department of ECE or the Office of Financial Aid (http://www.du.edu/apply/gradfinaid/graduate/index.html).

UNIVERSITY *of* DENVER

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DEGREE REQUIREMENTS

MASTER OF SCIENCE

The Department of ECE offers both part-time and full-time programs. The Department recognizes that a student may be employed full-time while studying for a degree. Therefore, most courses are offered at times and on days that will permit a student to complete the program by taking courses either late in the day or outside normal business hours.. The MS degree programs can generally be completed in about four years if one course is taken each quarter, but it is usually possible to take two courses per quarter, bringing completion time closer to the more common duration of two years. Also, students who select the one-year non-thesis will be able to graduate within 12 months, four academic quarters. For part-time students who are working in industry positions and who have chosen the thesis option, a topic related to the job function may be acceptable as the thesis research topic. Furthermore, a qualified staff member at the place of employment may be approved to serve as an adjunct faculty on the thesis committee.

Students not interested in pursuing a degree but interested in taking an occasional course may register as special status students by following an abbreviated admissions process. However, only 15 QH earned as a special status student may be applied toward a MS or PhD degree.

Minimum Credit Requirements
Every candidate for the MS degree must complete 45 QH of credit, at least 36 of which must be completed at the University of Denver.

Admission to the Master's Programs
A Bachelor of Science (BS) degree in Computer Engineering (BSCpE), Electrical Engineering (BSEE), or closely related field is required for admission to the programs. Those students whose backgrounds differ significantly from EAC/ABET-accredited BS Computer or Electrical Engineering programs may be required to complete prerequisite undergraduate courses. Such courses are not considered part of the 45 QH requirements for the degree. A competency examination may be required of candidates who do not possess a 3.0 GPA or a BS in Electrical, Electronic or Computer Engineering from an EAC/ABET accredited program. Students with BS degrees in Physics, Mathematics, Computer Science, Engineering Science, Electrical Engineering Technology, Engineering Physics or similar BS degrees may also be admitted. However, these students should be able to demonstrate competency in the following basic subjects by passing an appropriate competency examination:

MSCpE
- Circuits and Electronics
- Digital Systems
- Computer Organization
- A high- or low-level computer language

MSEE
- Digital Design Methods
- Physical Electronics
- Introductory Electromagnetics
- Signals and Systems
- Principles of Communications
- Circuits and Electronics

MSE
- Controls
- Robotics
- Signals and Systems
- Circuits and Electronics
- Digital Design Methods
- Mechanics
- Electromagnetics

Students may be admitted provisionally while they take the appropriate prerequisite courses should it be determined from the competency examination or from the prior academic records that certain needed skills are lacking. Through the satisfactory completion of the stated provisional requirements, the student's status will be changed from provisional to regular status.

Master of Science in Computer Engineering, Electrical Engineering, Mechatronic Systems Engineering, or Engineering

The Master of Science in Computer Engineering (MSCpE), Electrical Engineering (MSEE), or Mechatronic Systems Engineering (MSMSE) is designed to advance the student's knowledge in several areas of engineering. Each degree provides breadth while permitting the student to achieve depth in one of several specialization areas. These specialization areas, with thematic sequences of courses, have been selected to coincide with those of high current interest as well as those emerging technologies that hold promise of increasing importance for the future. The purpose of these programs is to serve the profession of engineering and the Colorado community through advanced study in computer engineering, electrical engineering, and other related fields. Each program prepares the student for academic and industrial advancement. All programs offer a thesis and a non-thesis option.

Program Structure
Candidates may elect either the thesis or non-thesis option. This choice may be made at any time, although a delay in declaration may impact the completion date. Students who are GTAs or who receive financial support from a University research grant, such as GRAs, are required to elect the thesis option. These programs are designed to be completed in about six quarters if two courses (usually 8 QH) are taken each quarter.

Non-Thesis Option
The non-thesis option is the more flexible of the two options. This program is designed with the working professional in mind. For this option, a grade of B or better must be obtained in each course in order for that course to count toward the requirement of 45 QH. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree. Each student must take a minimum of 24 quarter hours at the 4000-level.

One Year (four quarters) – Non-thesis Option
Effective with the Academic Year 2013-14, the Department of Electrical and Computer Engineering (ECE) offers a one-year, non-thesis option. Students who select the one-year program will be able to graduate within 12 months, four academic quarters, as there are enough courses offered in each specialization to meet the 20 QH depth requirement. The breadth requirement (14 QH) is fulfilled by taking courses offered in other specializations. In addition, every year courses that satisfy the mathematics requirement (3 QH) are offered. The MS non-thesis structure is shown below. QH

DEGREE REQUIREMENTS (Continued)

in each category denote minimum requirements that must be satisfied. Any changes in the student's plan of study must be approved a-prior by the student's advisor.

The basic structure of the minimum 45 QH for the non-thesis option is as follows:

Core Requirement Based on Degree	Minimum QH
Each degree program has two required classes. Please see program for specifics.	8 QH
Depth Requirement - Specialization Area	20 QH
Mathematics Requirement	
Requires one approved course at the 3000-level or higher	3 QH (*)
Breadth Requirement	14QH
Total QH, non-thesis option	45 QH

(*) This indicates minimum number of quarter hours. Any credits over the required 3 QH from the mathematics courses will count toward the breadth requirement.

Thesis Option

A thesis permits a candidate to obtain depth in an area of study and it is especially useful for individuals who seek to pursue a subsequent degree, for example, a PhD degree. Thesis candidates work closely with a thesis advisor. The thesis option is required for all GRAs and GTAs. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the 45 QH hour requirements. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree. Each student must take a minimum of 16 quarter hours at the 4000-level.The basic structure of the minimum 45 QH for the thesis option is as follows:

Core Requirement based on Degree	Minimum QH
Each degree program has two required classes. Pease see program for specifics.	8 QH
Depth Requirement- Specialization Area	16 QH
Breadth Requirement	6 QH (*)
Thesis	15 QH
Total QH, thesis option	45 QH

(*) The breadth requirement must be pre-approved by the student's advisor.

It is strongly recommended that students choose math related courses to satisfy the breadth requirement

If a student who has elected to pursue a thesis option, then at any time thereafter elects to change to a non-thesis option, all requirements for the non-thesis must be met. Any independent research taken may be forfeited and students must adhere to the grade requirements of the non-thesis option.

Breadth Requirement (Non-Thesis and Thesis Option)

Breadth Requirement courses (each with not less than 3 QH of credit) may be chosen from courses offered in other specialization areas. A course that appears in more than one specialization area may only be counted toward either the specialization requirement or the breadth requirement. The remaining courses are chosen from appropriate courses numbered 3000 or higher, offered by the Department Mechanical & Materials Engineering, Department of Computer Science or NSM (Natural Sciences and Mathematics). Prior approval by the student's advisor is required.

Master of Science in Computer Engineering (MS CpE)

The MSCpE program offers one area of specialization:
- Intelligent Information System Design

The student's degree program will be a combination of the core courses, specialization areas (depth requirement) and the breadth requirement. Each student is required to complete the 2 core courses. Students may choose from any of the courses from their area of specialization but should keep in mind the 4000-level requirement of the degree.

Core courses for all Computer Engineering Students

The following courses are required for all computer engineering students:

> ENCE 4110 Modern Digital Systems Design
> ENGR 3620 Advanced Engineering Mathematics

Specialization in Intelligent Information System Design

This area of specialization prepares students with fundamental and working knowledge of methods for analysis, design, and implementation of intelligent systems (IS). Particular attention is given to signal and information processing in IS, design of IS, and implementation of IS using state-of-the-art technology. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

> ENCE 3321 Network Design
> ENCE 4231 Embedded Systems Programming
> ENCE 4250 Advanced Hardware Description Language (HDL) Modeling and Synthesis
> ENCE 4501 Advanced VSLI Design
> ENCE 4620 Advanced Computer Vision
> ENCE 4900 Machine Learning
> ENEE 3670 Introduction to Digital Signal Processing

Master of Science in Electrical Engineering (MS ENEE)

The MSEE program offers four areas of specialization:
- Control System Analysis and Synthesis
- Electric Power and Energy Systems
- Optics/Optoelectronics
- Modern Communications System Design

Each student must choose an area of specialization. The student's degree program will be a combination of the core courses, specialization areas (depth requirement) and the breadth requirement. Each student is required to complete the 2 core courses. Students may choose from any of the courses from their area of specialization but should keep in mind the 4000-level requirement of the degree.

Core courses for all Electrical Engineering Students

The following courses are required for all electrical engineering students, regardless of area of specialization:

> ENEE 4640 Electromagnetic Compatibility
> ENGR 3620 Advanced Engineering Mathematics

Specialization in Control System Analysis and Synthesis

This area of specialization prepares students for basic and applied research and development of complex systems, including, electrical, mechanical, bio-inspired, mechatronic, and robotic systems, as well as unmanned systems. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

> ENCE 4231 Embedded Systems Programming
> ENEE 3670 Introduction to Digital Signal Processing
> ENEE 4630 Optical Networking
> ENGR 3721/3722 Controls and Controls Systems Laboratory
> ENGR 4730 Introduction to Robotics
> ENGR 4350 Reliability
> ENGR 4620 Optimization
> ENGR 4735 Linear Systems

*This course may count toward the specialization with advisors preapproval. This course may not or may not be offered on a regular basis.

Specialization in Electric Power and Energy

This area of specialization prepares students with the basic foundation and advanced knowledge, required for the research and development in the area of power systems, renewable energy systems, and power electronic devices. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

> ENGR 3510 Renewable and Efficient Power and Energy Systems
> ENGR 3540 Electric Power Systems
> ENGR 3721/3722 Controls and Controls Systems Laboratory
> ENGR 4530 Introduction to Power and Energy
> ENGR 4545 Electric Power Economy
> ENGR 4560 Power Generation Operation and Control
> ENGR 4735 Linear Systems

DEGREE REQUIREMENTS (Continued)

Specialization in Optoelectronics & Photonics

This area of specialization prepares students for research, development, and design of devices and systems operating based on wave theory; focusing on laser, optics, light wave devises, and systems.

ENEE 4030 Optoelectronics
ENEE 4035 Nanophotonics
ENGR 4200 Introduction to Nanotechnology
ENCE 4250 Advanced Hardware Description Language (HDL) Modeling and Synthesis
ENEE 4630 Optical Networking
ENGR 4735 Linear Systems

Specialization in Modern Communications Systems Design

This area of specialization prepares students for research, development and design of devices and systems that operate using wave theory: laser, optics and light wave devices, electromagnetic theory, waveguides and antennas. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

ENCE 3321 Network DesignENEE 3111 Signals & Systems
ENEE 3141 Digital Communications
ENEE 4030 Optoelectronics
ENEE 4035 Nanophotonics
ENEE 4620 Advanced Optical Fiber Communication
ENEE 4625 Radio over Fiber Communication
ENEE 4630 Optical Networking

Master of Science in Mechatronic Systems Engineering (MS MSE)

This area of specialization is designed to meet the needs of industry and federal research laboratories for engineers with multidisciplinary experience and ability to design and integrate complex systems requiring knowledge from diverse engineering disciplines. Said differently, mechatronic systems involves integration of mechanical, electrical, and computer engineering to design complex systems that perform real-world tasks. This program includes a broad set of common course requirements along with a selection of appropriate technical electives providing both breadth and depth of knowledge in a student's area of interest.

The MSE program offers one area of specialization:
• Mechatronic System Design

This program is a combination of core courses, specialization areas (depth requirement) and technical electives (breadth requirement). Each student is required to complete two core courses. Students, along with their advisor, should develop a plan of study choosing thematic sequences of courses from different specialization areas, but they should keep in mind the 4000-level requirement of the degree.

Core courses for all Mechatronic Systems Engineering Students

The following courses are required for all mechatronic systems engineering students regardless of area of specialization:

ENEE 4641 Electromagnetic Compatibility OR
ENCE 4110 Modern Digital Systems Design
ENGR 3620 Advanced Engineering Mathematics

Specialization in Mechatronic System Design

ENCE 4620 Advanced Computer Vision
ENCE 4250 Advanced Hardware Description Language (HDL) Modeling and Synthesis
ENCE 4231 Embedded Systems Programming
ENCE 4900 Machine Learning
ENGR 3350 Reliability
ENGR 3630 Finite Element Methods
ENGR 4620 Optimization
ENGR 4730 Introduction to Robotics
ENGR 4735 Linear Systems
ENME 4020 Advanced Finite Element Analysis
ENMT 4220 Mechatronics II

*This course may count toward the specialization with advisors preapproval. This course may not or may not be offered on a regular basis.

Engineering - Concentration in Engineering Management

This program allows students to pursue a concentration in engineering management. The concentration in engineering management is designed to meet the increasing needs of students to enhance their career opportunities as managers or as entrepreneurs by supplementing advanced engineering knowledge with a fundamental understanding of business principles within the context of technology enterprises. Drawing upon the strengths of both the Ritchie School of Engineering and Computer Science (RSECS) and the Daniels College of Business (DCB), the program provides relevant content for graduates to lead technology enterprises. There is only a non-thesis option available for this program. The program structure is as follows:

Engineering Focus (depth requirement)	Minimum QH
• A minimum of four 4000-level courses	24 QH
• At the time of admission students must choose an engineering focus area. Students must choose an Engineering Focus from: computer, electrical or mechanical engineering. This focus area should be me mentioned in the Statement of Purpose	
• At least 6 courses must be in the Engineering Focus Area of either computer, electrical or mechanical engineering. Students will be assigned to an engineering advisor which student must consult with prior to choosing courses.	

Engineering Mathematics Requirement

Must be at the 4000-level and have   3 QH
advisors approval

Management Focus   18 QH

Students may choose any 4000-level management
courses offered by the Daniels College of Business

Total QH   45 QH

The engineering focus must consist of a set of coordinated and related engineering courses designed to give the student depth in a particular engineering discipline (CpE, EE. MSE or ME). Students must choose and follow an area of specialization from a given discipline (the specializations are listed above), but this requirement may be waived with approval by the student's engineering advisor if the student wishes to pursue a coherent inter-disciplinary curriculum.

Additional Mathematics Requirement:

All MS non-thesis candidates must complete an advanced mathematics requirement. Students may choose from the following courses:

ENGR 3620	Advanced Engineering Mathematics
ENGR 4620	Optimization
ENEE 3670/4800	Introduction to DSP
ENGR 3630	Finite Element Methods
ENGR 3800	Topics in Engineering: Numerical Methods
ENGR 4350	Reliability
ENGR 4735	Linear Systems
ENGR 4740	Principles of Adaptive and Optimal Control Systems
ENGR 4745	Advanced Non-Linear Control System
ENME 4020	Advanced Finite Element Analysis
MATH 3120	Introduction to Topology
MATH 3151	Advanced Linear Algebra
MATH 3152	Linear Algebra II
MATH 3161	Introduction to Real Analysis
MATH 3166	Group Theory
MATH 3400	Introduction to Geometry
MATH 3705	Topics in Mathematics
MATH 3720	Coding Theory
MATH 3851	Functions Complex Variable I
MATH 3852	Functions Complex Variable II

DOCTOR OF PHILOSOPHY DEGREE REQUIREMENTS

The objective of the PhD in ECE or MSE degree programs are to provide an educational environment that encourages students to develop the ability to contribute to the advancement of science, engineering and technology, through independent research. The PhD students of the 21st century may pursue academic, research, entrepreneurial, and/or industrial careers. We offer opportunities to develop individualized plans of study based on the students' previous experience and desired research areas. The plan of study allows students to work on interdisciplinary research, while also satisfying the PhD in ECE or MSE degree requirements.

Admission to the PhD Program

Students with a MS in CpE, MS in MSE, MS in EE, MS in ME, or closely related areas may apply for admission to the PhD in ECE or PhD in MSE programs. Admission with only a BS in this field is also possible, but students with only a BS degree are strongly encouraged to enroll first in the MS (CpE, EE, MSE) programs. Admission to the PhD programs is based on review of the application and associated references. Normally, a GPA of at least 3.0 is required. All graduate engineering courses presuppose mastery of the subject matter of a modern ABET-accredited curriculum in engineering. Students with a BS in other engineering or related science fields and students with a BSCpE, BSEE, or BSME who have not taken graduate academic work for some time may be required to complete preparatory courses that are prerequisites for the core courses of the engineering concentrations on which the qualifying exams are based. These courses carry no credit toward the graduate degree.

Program Structure

Research requires an in-depth study of engineering problems with a broad knowledge base in science and engineering. Therefore, advanced courses are offered to strengthen the fundamentals and to broaden the engineering and science perspective. The minimum credit requirements are different for individuals entering a program with a closely related master's degree and for those entering with a bachelor's only. All requirements for the degree must be completed within seven years (eight years without a master's degree) from admission to candidacy. A grade of C or better must be obtained in each course in order for that course to count toward the credit hour requirements. An overall minimum GPA of 3.0 is also required for graduation.

PhD in ECE

The PhD in ECE is appealing to students because it offers the much needed specialization component and the 'degree identity' required to be competitive in the job market. Graduates from this program will be well equipped to follow academic careers, or be hired in federal laboratories, industry and the private sector.

PhD in MSE

The PhD in MSE is at the forefront and intersection of the coupled disciplines of Electrical, Mechanical, Computer Engineering, and Computer Science. This unique degree is appealing to students because they will acquire the knowledge and ability to deal with and solve highly complex problems where integration is a key component. This degree provides a holistic approach to graduate education focusing on the ability to cover both breadth and depth of knowledge. Graduates of this program will lay the foundation for the modern engineering departments of the future, where 'integration' will be the key ingredient of studies.

Program requirements

All PhD students who have been admitted to the PhD in ECE or PhD in MSE programs must successfully complete three milestones before the PhD degree can be conferred. These milestones refer to:

- Demonstrating that the student is qualified to begin PhD studies
- Demonstrating that the student may identify and formulate a research problem
- Demonstrating that the student can defend her/his thesis

These three milestones are referred to as the "PhD Qualifying Exam", the "Comprehensive Exam" (also known as the "PhD Proposal"), and the "Thesis Defense".

If a student is entering the PhD program without a relevant master's degree, the student should work with their advisor in order to meet the degree requirements for a master's degree. All requirements for the given master's degree must be met in order for the students to receive the degree.

Qualifying Examination

Each student must demonstrate sufficient breadth and depth of basic engineering knowledge relevant to electrical and computer engineering. Each student must demonstrate ability to organize and present her/his thoughts in a convincing manner. The PhD Qualifying Exam achieves this through three components: a written Common Exam of basic engineering knowledge (breadth), two written Specific Area Exams (depth), and an oral Design Exam (breadth, depth, organization and presentation). Failure to pass any component of the PhD Qualifying Exam will prevent the student from continuing in the PhD program.

All PhD students who are admitted into the Department of Electrical and Computer Engineering must pass the PhD Qualifying Exam. There are three components of the PhD Qualifying Exam consisting of four test subject areas. The three components are

PhD Common Exam- This is a common two-hour written exam. Each student, with advice from his/her advisor must choose one of the three subject areas. The Common Exam will be graded as pass/fail; with 70% constituting as passing grade.
- Engineering Mathematics (Calculus, Engineering Analysis, Linear Algebra)
- Circuits and Electronics
- Digital Design, Computer Organization, and HDL

PhD Specific Area Exam-This part of the exam will consist of two written subject area texts lasting two hours each. Students must pick two specific subject areas and cannot be the same subject area as the topic chosen for the PhD Common Exam. The Specific Area Exam will be graded as pass/fail; with 70% constituting as passing grade.
- Digital Design, Computer Organization, and HDL (only if NOT taken for the common component)
- Circuits and Electronics (only if NOT taken for the common component)
- Microprocessors
- Data Structures, Algorithms, & Operating Systems
- Control, Signals & Systems
- Electromagnetics
- Power & Energy Systems
- Optoelectronics
- Optical Fiber Communication
- Communication & DSP

- Robotics
- Image Processing & Computer Vision
- Pattern Recognition

PhD Specialization Design Exam-This portion of the exam will be an open-ended design problem developed by the candidate's advisor. The Design Exam will be based on the candidate's area of research. This exam will be evaluated by a committee of three faculty (one must be the candidate's advisor) in both written and oral form. The candidate will have five days to complete the written report and an additional two days to prepare the presentation. If the written design exam is turned in late for any reason, it will be considered as an automatic fail. The Specialization Design Exam will be graded on a pass/fail scale.

The purpose of this design examination is to demonstrate the candidate's ability to follow good design procedures at the level of an undergraduate senior design course and to explain/justify the tradeoffs that are tantamount to design. For the purposes of this examination, "good design procedures" shall include the following steps as outlined in the DU ENGR 3313/3323/3333 sequence in the undergraduate curriculum:

- Conceptual Design
- Requirements Analysis
- Specification
- Brainstorming
- Architectural Design
- Detailed Design
- Test and Validation
- Maintenance and Support

In general, it will not be possible to fully execute a design solution to an open-ended design problem in one week. The emphasis of this exam is on the candidate's ability to complete the above steps to some convincing level of detail, the candidate's ability to explain/justify the tradeoffs considered at each step of the process, and the candidate's ability to communicate the completeness of the design exercise to the committee at a level appropriate for a beginning graduate student in engineering. As part of this exercise, comparisons to the existing body of literature are expected.

If a student is unable to pass the PhD Common Exam and/or any of the PhD Specific Area Exams, the student must take the same exam(s) during the second attempt; the student is not allowed to switch subject areas.

All PhD students must attempt the PhD Qualifying Exam by the end of their first year. If a student is unsuccessful at passing all four test areas, the student will be given an additional year to pass the PhD Qualifying Exam. All students must take and pass the PhD Qualifying Exam by the end of their second year. A student shall be considered to have passed the PhD Qualifying Exam only after all four test areas have been successfully completed within the given time constraints identified.

Comprehensive Examination

The purpose of the Comprehensive Examination is to ascertain the potential of the student for PhD quality research. At least two quarters prior to the final defense, the student shall schedule and take the Comprehensive Examination. This oral and written examination will be attended by a minimum of three faculty members, the same faculty who will attend the student's final dissertation defense. The Comprehensive Exam may be open to other students based on the

requirements of the student's advisor. The student is expected to make a 30 to 40 minute concise presentation on her/his dissertation topic. The oral and written presentation will highlight previous work in this area, demonstrate a need for the given research, and explain how the given research will contribute to the advancement of the area. The student will also present completed work and results, anticipated work and results, and a detailed plan for project completion. In addition, the student will be expected to answer general fundamental questions in the area of her/his concentration and detailed questions in the area of the student's graduate course work.

The PhD Qualifying Examination must be taken and passed prior to the student taking the Comprehensive Examination. The Comprehensive Examination can be taken at most 2 times. If the student does not pass the Comprehensive Exam on the second try, the student will be terminated from the program. The comprehensive exam will be graded on a pass/fail system, revisions maybe required.

Dissertation

The student is required to complete and defend a dissertation of publishable quality based on the student's original research. The dissertation must be completed in written form in accordance with the University's Graduate School guidelines. A summary of the dissertation must be presented in a public seminar and subsequently defended by the student in the final oral examination. The examining committee will consist of the student's entire PhD committee.

Residence Requirement

Enrollment in at least six quarters (four semesters), including at least two consecutive quarters (one semester) of full-time attendance is required for graduation.

PhD Committee

The PhD committee should consist of at least four faculty members. Three faculty members must be from within the student's specialty area; these can include the student's advisor, other faculty in that degree program and, if necessary, off-campus experts. Finally, for the final oral defense of the thesis, an oral defense chair, who must be a tenured faculty member outside the Department of Electrical and Computer Engineering and Mechanical and Materials Engineering, needs to be identified in consultation with the DU Graduate Studies Office. The PhD committee must approve the student's plan of study and research plan and must be in place before the PhD comprehensive exam.

Minimum credit requirements
Students with a Bachelor of Science in Engineering/Science

For students admitted to the PhD program with a bachelor's degree, 90 QH are required, 72 of which must be completed at the University of Denver. A minimum of 48 QH must be at the 4000-level or higher and may include as many dissertation research hours (Independent Research and Independent Study) as considered appropriate by the advisor. The student with his/her advisor will develop an appropriate plan of study with core requirements, an area of specialization (depth requirement), breadth requirement and advanced mathematics. The core will consist of 8 QH of coursework. The area of specialization will consist of 16 QH of coursework. An additional 6 QH of coursework (excluding independent research) is required as related breadth requirement. The student must complete a minimum of 16 HQ at the 4000-level courses, excluding independent research. Prior to completion of the comprehensive exam, the plan of study must be approved by the student's PhD committee.

Students with a Master of Science in Engineering/Science

If a student is admitted with a closely related master's degree, up to 45 hours may be transferred and applied to the doctorate degree. A minimum of 45 quarter hours is required at the University of Denver. The student with his or her advisor will develop an appropriate program consisting of a minimum of 45 quarter hours at the 4000-level, which

may include as many dissertation research hours (Independent Research and Independent Study) as considered appropriate by the advisor. The student with his or her advisor will develop an appropriate plan of study with an area of specialization, breadth requirements and advanced mathematics. Prior to completion of the comprehensive exam, the student's plan of study must be approved by the student's PhD committee.

ECE FACULTY

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Rensselaer Polytechnic Institute

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Jason Zhang, PhD
Assistant Professor, electrical engineering
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JOINT FACULTY APPOINTMENTS

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Joint appointment with ECE
University of Oregon

Corinne Lengsfeld, PhD
Professor, mechanical engineering
Joint appointment with ECE
University of California, Irvine

Matthew Rutherford, PhD
Assistant professor, computer science
Joint appointment with ECE
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Ramki Thurimella, PhD
Professor and department chair, computer science
Joint appointment with ECE
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Yun-Bo YI, PhD
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RESEARCH PROFESSORS

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Yale University

Mark Gentz, PhD
University of Denver

George Rinard, PhD
University of Missouri

Przemyslaw Rupnowski, PhD
University of Denver

J.M. Reeves, PhD
University of Washington, Seattle

COURSE DESCRIPTIONS

ENCE 3220 Microprocessor Systems II (4 qtr. hrs.)
Introduction to microprocessors and to the design and operation of computer systems. A study of the microprocessor and its basic support components. Analysis CPU architectures of modern computers. Assembly language programming. Use of an assembler and other development tools for programming and developing microprocessor-based systems. Laboratory. Prerequisite: ENCE 3210.

ENCE 3250 HDL Modeling & Synthesis (3 qtr. hrs.)
Introduction to Hardware Design Language (HDL). Language syntax and synthesis. Applications related to digital system implementation are developed. Project. Prerequisite: ENCE 2101 or instructor's permission.

ENCE 3261 Fault Tolerant Computing (3 qtr. hrs.)
Basic concepts of dependable computing. Reliability of nonredundant and redundant systems. Dealing with circuit-level defects. Logic-level fault testing and tolerance. Error detection and correction. Diagnosis and reconfiguration for system-level malfunctions. Degradation management. Failure modeling and risk assessment.

ENCE 3501 VLSI Design (3 qtr. hrs.)
Design of Very Large Scale Integration systems. Examination of layout and simulation of digital VLSI circuits using a comprehensive set of CAD tools in a laboratory setting. Studies of layouts of CMOS combinational and sequential circuits using automatic layout generators. Fundamental structures of the layout of registers, adders, decoders, ROM, PLA's, counters, RAM and ALU. Application of statistics and probability to chip performance. CAD tools allow logic verification and timing simulation of the circuits designed. Prerequisite: ENCE 3220.

ENCE 3610 Multimedia Systems (3 qtr. hrs.)
Interactive multimedia technologies include hardware, software, standards, concepts and issues, compression, decompression, user interface design, query by content, multimedia indexing, and distributed multimedia.

ENCE 3620 Computer Vision (4 qtr. hrs.)
This course is an introduction to the basic concepts in image processing and computer vision. First, an introduction to low-level image analysis methods, including radiometry and geometric image formation, edge detection, feature detection, and image segmentation are presented. Then, geometric-based image transformations (e.g., image warping and morphing) for image synthesis will be presented in the course. Furthermore, methods for reconstructing three-dimensional scenes including camera calibration, Epipolar geometry, and stereo feature matching are introduced. Other important topics include optical flow, shape from shading, and three-dimensional object recognition. In conclusion, students learn and practice image processing and computer vision techniques that can be used in other areas such as robotics, pattern recognition, and sensor networks. Prerequisite: ENEE 3311.

ENCE 3630 Pattern Recognition (4 qtr. hrs.)
This class provides an introduction to classical pattern recognition. Pattern recognition is the assignment of a physical object or event to one of several prescribed categories. Applications includes automated object recognition in image and videos, face identification, and optical character recognition. Major topics include Bayesian decision theory, Parametric estimation and supervised learning, Linear discriminant functions, Nonparametric methods, Feature extraction for representation and classification, Support Vector Machines.

ENCE 4100 High Speed Digital Design (4 qtr. hrs.)
Fundamental topics related to the development of high speed digital systems. Topics include signal integrity and reliability related to crosstalk, parasitic, and electromagnetic interference caused by device clocking speed and system complexity. Project.

ENCE 4110 Modern Digital Systems Design (4 qtr. hrs.)
This course focuses on the design of digital systems using combinational, sequential, and programmable logic devices and Hardware Description Languages (HDL). Techniques for logic design including asynchronous logic, physical world interfaces to digital systems, and system performance analysis methods are studied. Students also learn HDL-Verilog to program CPLD devices and FPGA systems.

ENCE 4231 Embedded Systems Programming (4 qtr. hrs.)
Design, construction and testing of microprocessor systems. Hardware limitations of the single-chip system. Includes micro-controllers, programming for small systems, interfacing, communications, validating hardware and software, microprogramming of controller chips, design methods and testing of embedded systems.

ENCE 4250 Advanced Hardware Description Language (HDL) Modeling and Synthesis (4 qtr. hrs.)
This course covers advanced concepts in Hardware Description and Language (HDl) modeling and Synthesis. It covers topics including but not limited to digital system

design, simulation, and synthesis using Verilog HDL and VHDL. The course also covers RTL design, behavioral description, system Verilog, and timing analysis using CAD tools.

ENCE 4501 Advanced VLSI Design (4 qtr. hrs.)

Advanced techniques in the fabrication and design of VLSI circuits and systems. Modeling of parasitic components. Floor-planning, clock distribution, routing, and low power design. Prerequisite: ENCE 3501 or permission of instructor.

ENCE 4601 Detection and Estimation Theory (4 qtr. hrs.)

The subject of the detection and estimation theory course is on signal and information processing for the purpose of making desired inferences. The purpose of this course is to provide the fundamentals of theory and principles underlying the techniques for such processing. The following topics are involved in this course: receiver operating characteristics, hypothesis testing, Neyman-Pearson theorem, detection of deterministic signals with known parameters in Guassian noise, matched filters principles, detection of random signals with known characteristics, estimator-correlator, linear models, estimation bias, variance, Cramer-Rao bounds and Fisher matrix, Bayesian estimation, maximum likelihood estimation, minimum mean-squared estimation, detection of deterministic signals with unknown parameters, signal parameter estimation, Bayesian approach and generalized likelihood ratio test, detection of random signals with unknown characteristics, unknown noise parameters; signal processing applications. Prerequisite: basic understanding of probability theory and statistics, or permission of instructor.

ENCE 4620 Advanced Computer Vision (4 qtr. hrs.)

This course covers advanced concepts in image processing and computer vision including but not limited to image radiometry and geometric formation, edge detection, geometric based transformations (e.g., image warping and morphing), camera calibration, Epipolar geometry, and stereo feature matching. Other advanced topics include optical flow, shape from shading, and three-dimensional object recognition. In conclusion, students learn and practice advanced topics in image processing and computer vision techniques that can be used in other areas such as robotics, pattern recognition, and sensor networks. Prerequisite: ENEE 3311.

ENCE 4630 Advanced Pattern Recognition (4 qtr. hrs.)

This class covers advanced topics in pattern recognition including but not limited to Bayesian decision theory, parametric estimation and supervised learning, linear discriminant functions, nonparametric methods, feature extraction for representation and classification, manifold learning, bag of words, and Support Vector Machines.

ENCE 4680 Time-Frequency Signal Analysis (4 qtr. hrs.)

This course focuses on time-frequency signal processing methods. Many TFRs and their usefulness in many applications is covered. Course topics include: signals and signal properties; uncertainty principle. Review of 1-D transforms: Fourier transform (FT), group delay, instantaneous frequency. Desirable properties: linear vs. quadratic TFRs. Linear TFRs: Short-timer Fourier transform (STFT); Wavelet transform; filter banks. Spectrogram: relation to STFT; tradeoff between TF resolution and cross-term attenuation; application examples. Wignor distribution (WD): definition; properties; signal examples; relation to narrowband ambiguity function; cross-term geometry; applications; Smoothed WDs. Scalogram: relation to wavelet transform; properties; TF resolution' applications. Adaptive TRFs: adaptive spectrogram; positive TRFs; short-time techniques; time-frequency distribution series. Reassignment method; matching pursuit algorithms. TFRs in real-world applications: wireless communications, biomedicine, radar, sonar, detection, estimation, classification, speech processing, image processing, structural health monitoring, and many more. Prerequisites: basic knowledge of signal and systems, and digital signal processing, or permission of instructor.

ENCE 4800 Advanced Topics (CPE) (1 to 5 qtr. hrs.)

Various topics in computer engineering as announced. May be taken more than once.

ENCE 4900 Machine Learning (4 qtr. hrs.)

This course provides a broad introduction to machine learning. Topics include: supervised learning (linear regression, logistic regression, parametric/non-parametric, neural networks, support vector machines); unsupervised learning (clustering, dimensionality reduction, kernel methods); anomaly detection and recommender systems. The course also discusses recent applications of machine learning. Recommended prerequisite: basic probability theory and statistics.

ENCE 4991 Independent Study (1 to 10 qtr. hrs.)

ENCE 4992 Directed Study (1 to 10 qtr. hrs.)

ENCE 4995 Independent Research (1 to 18 qtr. hrs.)

ENEE 3011 Physical Electronics (0 or 4 qtr. hrs.)

The basic physical concepts of electronics, electrons and holes in semiconductors, transport and optical processes. Concentration on device concepts, including material synthesis and device processing, P-N junction diodes, junctions with other materials, bipolar transistors, field effect transistors (JFET, MESFET, MOSFET) and optoelectronic effect transistors (JFET, MESFET, MOSFET) and optoelectronic devices (lasers, detectors). Prerequisites: CHEM 1010, CHEM 1610, PHYS 1213, PHYS 1214 or permission of instructor.

ENEE 3111 Signals & Systems (0 or 4 qtr. hrs.)
Introduces continuous time and discrete time linear system analysis, Fourier series, Fourier transforms and Laplace transforms. Specific engineering tools for discrete time linear system analysis include discrete time convolution, Z-transform techniques, discrete Fourier transform and fast Fourier transform (DFT/FFT), and the design and analysis of analog and digital filters for real-world signal processing applications. Prerequisites: ENEE 2021, MATH 2070.

ENEE 3141 Digital Communications (3 qtr. hrs.)
Introductory course on modern digital communication systems. The basic communication system theory, probability and random processes, baseband digital data transmission, coherent and non-coherent digital modulation techniques and analysis of bit error probability. Bandwidth efficiency and transmission of digital data through band-limited channels. Prerequisites: ENEE 3111, ENGR 3610 or permission of instructor.

ENEE 3611 Analysis and Design of Antennas and Antenna Arrays (4 qtr. hrs.)
Maxwell's equations applied to antenna analysis and design. Topics include fundamental parameters of antennas, radiation integrals and auxiliary potential functions, analysis and design of linear wire antennas, loop antennas, arrays, broadband antennas, frequency independent antennas, aperture antennas and horns. Integrated lab included. Prerequisite: ENEE 2611.

ENEE 3620 Optical Fiber Communications (4 qtr. hrs.)
A comprehensive treatment of the theory and behavior of basic constituents, such as optical fibers, light sources, photodetectors, connecting and coupling devices, and optical amplifiers. The basic design principles of digital and analog optical fiber transmission links. The operating principles of wavelength-division multiplexing (WDM) and the components needed for its realization. Descriptions of the architectures and performance characteristics of complex optical networks for connecting users with a wide range of transmission needs (SONET/SDH). Discussions of advanced optical communication techniques, such as soliton transmission, optical code-division multiplexing (optical CDMA) and ultra-fast optical time-division multiplexing (OTDM). Laboratory. Prerequisite: ENEE 3030 or permission of instructor.

ENEE 3641 Introduction to Electromagnetic Compatibility (4 qtr. hrs.)
The study of the design of electronic systems so that they operate compatibly with other electronic systems and also comply with various governmental regulations on radiated and conducted emissions. Topics may include Electromagnetic Compatibility (EMC) requirements for electronic systems; non-ideal behavior of components; radiated emissions and susceptibility; conducted emissions and susceptibility; shielding and system design for EMC. Includes integrated lab. Prerequisites: ENEE 3111, ENEE 2611 and ENEE 2222.

ENEE 3660 Communications Systems Design (4 qtr. hrs.)
Design and performance evaluation of terrestrial and space communications systems; error correction coding; spread spectrum communication; link budget analysis and environmental effects. System design considerations include engineering judgment decisions to implement optimum communication configurations such as data rates, bandwidth, modulation schemes and operating frequencies. Prerequisite: ENEE 3130.

ENEE 4030 Optoelectronics (4 qtr. hrs.)
Optical fibers: structures, waveguiding, and fabrication; attenuation and dispersion; optical sources (LED, LASER, Fiber laser); power launching and coupling; photodetectors (APD, PIN, MSM); and practical optical transmitter and receivers.

ENEE 4035 Nanophotonics (4 qtr. hrs.)
Nanophotonics provides high-speed, high-bandwidth, and ultra-small optoelectronic components. This course covers nanoscale processes, devices and their applications for harnessing and manipulating light on the nanoscale.

ENEE 4310 Information Theory and Coding (3 qtr. hrs.)
Information and entropy; coding theory; error detection, correction codes; channel capacity; application to communications engineering.

ENEE 4416 Advanced Digitial Signal Processing Topics (4 qtr. hrs.)

COURSE DESCRIPTIONS (Continued)

Study of linear discrete-time systems used to perform operation on random processes for the purposes of signal detection, estimation, spectral estimation, enhancement and parametric modeling of signals and systems, linear difference equations, Z-transforms, random sequences, state variables, matched filtering, Wiener filtering. Prerequisite: ENEE 3670.

ENEE 4460 Real-Time Digital Signal Processing (4 qtr. hrs.)
Digitial signal processing algorithms and processing of discrete data, finite word length effects on filters, fixed point arithmetic and floating-point arithmetic. Overview of different architectures of digital signal processors. Programming of the DSP processor, implementation of DSP algorithms on DSP hardware in labs. Prerequisite: ENEE 3111, ENEE 3670, or ENCE 3210.

ENEE 4620 Adv Optical Fiber Comm (4 qtr. hrs.)
A comprehensive treatment of the theory and behavior of basic constituents, such as optical fibers, light sources, photodetectors, connecting and coupling devices, and optical amplifiers. The basic design principles of digital and analog optical fiber transmission links. The operating principles of wavelength-division multiplexing (WDM) and the components needed for its realization. Descriptions of the architectures and performance characteristics of complex optical networks for connecting users who have a wide range of transmission needs (SONET/SDH). Discussions of advanced optical communication techniques, such as soliton transmission, optical code-division multiplexing (optical CDMA), and ultra-fast optical time division multiplexing (OTDM). Advanced Project. Graduate course: Prerequisite: instructor permission.

ENEE 4625 Radio over Fiber Comms. (4 qtr. hrs.)
This course provides comprehensive and technical foundation in Microwave photonic Applications: Radio over optical fiber communications (RoF) is a novel technology in the field of short-range communication applications. The main goal is to enable range extension of 1 to 3 orders of magnitude over a typical ultra wide wideband radio signal in the range of 3.1-10.6 GHz. This technology allows separation of low cost Base-Station (BS)s from the Central-Station (CS). In the RoF technology is targeting the Personal Area Network (PAN) market that is characterized by very low cost and low power (10 uW) access point. In RoF, the optical fiber is used to carry extremely wide RF signals (several GHz).

ENEE 4630 Optical Networking (4 qtr. hrs.)

This course provides a technical overview of optical networking. It gives students a solid understanding of optical networking field principles and practice. Underlying principles are reviewed along with common optical solutions and practices. It explains and provides practical tips on how to design and implement Networks. Examples are used to demonstrate key concepts of ATM, SONET/SDH and DWDM implementation. Prerequisite: ENEE 3011 or instructor approval.

ENEE 4640 Electromagnetic Compatibility (4 qtr. hrs.)
The study of the design of electronic systems so that they operate compatibly with other electronic systems and also comply with various governmental regulations on radiated and conducted emissions. Topics may include: Electromagnetic Compatibility (EMC) requirements for electronic systems; non-ideal behavior of components; radiated emissions and susceptibility; conducted emissions and susceptibility; shielding and system design for EMC. Final Project.

ENEE 4650 Radio Frequency Design in the Wireless World (4 qtr. hrs.)
Topics include the following: basic concepts in Radio Frequency deign and communications, transceiver architectures, low-noise amplifiers, mixers, oscillators, phase-locked loops, power amplifiers, and transceiver design examples. Final Project. Prerequisites: ENEE 2611, ENEE 2222, and ENEE 3111 or equivalents.

ENEE 4800 Advanced Topics (EE) (1 to 5 qtr. hrs.)
Various advanced topics in electrical engineering as announced. May be taken more than once.

ENEE 4991 Independent Study (1 to 10 qtr. hrs.)

ENEE 4992 Directed Study (1 to 10 qtr. hrs.)

ENEE 4995 Independent Research (1 to 18 qtr. hrs.)

ENEE 6991 Ph.D Independent Study (1 to 10 qtr. hrs.)

ENEE 6995 Ph.D Independent Research (1 to 10 qtr. hrs.)

ENGR 3210 Intro Nano-Electro-Mechanics (4 qtr. hrs.)
Familiarize science and engineering students with the electromechanical aspects of the emerging field of Nanotechnology (NEMS). NEMS is a relatively new and highly multidisciplinary field of science and technology with applications to state of the art and future sensors, actuators,

and electronics. Starting with an overview of nanotechnology and discussion on the shifts in the electromechanical behavior and transduction mechanisms when scaling the physical dimensions from centimeters to micro-meters and then down to nanometers. Several electromechanical transduction mechanisms at the micro and nanoscale are presented and discussed in an application based context. New electromechanical interactions appearing in the nano and molecular scale, such as intra-molecular forces and molecular motors, are discussed. A detailed discussion and overview of nanofabrication technologies and approaches are also provided. Prerequisite: must be an engineering or science major of at least junior standing.

ENGR 3510 Renewable and Efficient Power and Energy Systems (4 qtr. hrs.)

This course introduces the current and future sustainable electrical power systems. Fundamentals of renewable energy sources and storage systems are discussed. Interfaces of the new sources to the utility grid are covered. Prerequisite: ENEE 2021.

ENGR 3520 Introduction to Power Electronics (4 qtr. hrs.)

This covers fundamentals of power electronics. We discuss various switching converters topologies. Basic knowledge of Efficiency and small-signal modeling for the DC-DC switching converters is covered. Furthermore, magnetic and filter design are introduced. Prerequisites: ENEE 2211 and ENGR 3722.

ENGR 3525 Power Electronics and Renewable Energy Laboratory (1 qtr. hrs.)

In this course the fundamentals of switching converters and power electronics in a real laboratory set-up are covered. The course incorporates hardware design, analysis, and simulation of various switching converters as a power processing element for different energy sources. The energy sources are power utility, batteries, and solar panels. Prerequisite: ENGR 3520.

ENGR 3540 Electric Power Systems (4 qtr. hrs.)

This course covers methods of calculation of a comprehensive idea on the various aspects of power system problems and algorithms for solving these problems. Prerequisite: ENGR 3530.

ENGR 3550 Introduction to Machine Drive Control (4 qtr. hrs.)

This course provides the basic theory for the analysis and application of adjustable-speed drive systems employing power electronic converters and ac or dc machines. Prerequisites: ENGR 3520 and ENGR 3530.

ENGR 3731 Robotics Lab (1 qtr. hrs.)

Laboratory that complements the analysis, design, modeling and application of robotic manipulators. Implementation of the mathematical structures required to support robot operation. Topics include forward kinematics, inverse kinematics, motion kinematics, trajectory control and planning and kinetics. Applications include programming and task planning of a manufacturing robot manipulator. Corequisite: ENGR 3730 or permission of instructor.

ENGR 3970 Entrepreneurship for Engineers and Computer Scientists (4 qtr. hrs.)

The course presents an overview of fundamentals of understanding entrepreneurship and entrepreneurial characteristics; the focus is on aspects of engineering entrepreneurship, technology-based innovation and new product development. Topics to be covered: learning an industry; recognizing and creating opportunities; new product development process, phases and cycle, risks and benefits; 'testing' of an engineering-focused business concept; marketing, organizational plan strategies and financing for new start ups. Special attention is given to technological innovation, considering both incremental or routine innovation, and more radical or revolutionary changes in products and processes. Prerequisite: ENGR 3610 or permission of the instructor.

ENGR 4200 Introduction to Nanotechnology (4 qtr. hrs.)

The most important recent accomplishments so far in the application of nanotechnology in several disciplines are discussed. Then a brief overview of the most important instrumentation systems used by nanotechnologists is provided. The nature of nanoparticles, nanoparticle composites, carbon nanostructures, including carbon nanotubes and their composites is subsequently discussed. The course also deals with nanopolymers, nanobiological systems, and nanoelectronic materials and devices. The issues of modeling of nanomaterials and nanostructures is also covered. Multiscale modeling based on finite element simulations, Monte Carlo methods, molecular dynamics and quantum mechanics calculations are briefly addressed. Most importantly, students should obtain appreciation of developments in nanotechnology outside their present area of expertise.

ENGR 4210 Introduction to Nano-Electro-Mechanical-Systems (4 qtr. hrs.)

This course familiarizes science and engineering students to the electromechanical aspects of the emerging field of Nanotechnology (NEMS). NEMS is a relatively new and highly multidisciplinary field of science and technology with applications in the state of the art and future sensors, actuators, and electronics. This course starts with an overview of nanotechnology and discussion on the shifts in the electromechanical behavior and transduction mechanisms when scaling the physical dimensions from centimeters to micro-meters and then down to nanometers. Several electromechanical transduction mechanisms at the micro and nanoscale are presented and discussed in an application based context. New electromechanical interactions appearing in the nano and molecular scale, such as intra-molecular forces and molecular motors, are discussed. A detailed discussion and overview of nanofabrication technologies and approaches are also provided.

ENGR 4215 Nanoscale Electromechanical Systems and Nanofabrication Laboratory (4 qtr. hrs.)

This course provides science and engineering students with comprehensive hands-on experience in design, fabrication and characterization of Nanoscale Electromechanical Systems (NEMS). This laboratory-based course starts with a number of sessions including brief lectures reviewing the fundamentals and theories followed by pre-designed lab experiments. The students are then provided with a choice of different comprehensive design and implementation projects to be performed during the quarter. The projects include design, layout, fabrication, and characterization of the devices potentially resulting in novel findings and publications.

ENGR 4220 Introduction to Micro-Electro-Mechanical-Systems (4 qtr. hrs.)

This course introduces students to the multi-disciplinary field of Micro-Electro-Mechanical-Systems (MEMS) technology. MEMS and Microsystem technology is the integration of micro-scale electro-mechanical elements, sensors, actuators, and electronics on a common substrate or platform through semiconductor microfabrication technologies. The course gives a brief overview of the involved physical phenomena, electromechanical transduction mechanisms, design principles, as well as fabrication and manufacturing technologies.

ENGR 4530 Intro to Power and Energy (4 qtr. hrs.)

Basic concepts of AC systems, single-phase and three-phase networks, electromechanical energy conversion, electric power generation, transformers, transmission lines, AC machinery, DC motors, and contemporary topics in power and energy conversion.

ENGR 4545 Electric Power Economy (4 qtr. hrs.)

This course covers economy aspects of electric power industry and the implications for power and energy engineering in the market environment. Prerequisite: ENGR 3530 or ENGR 4530.

ENGR 4560 Power Generation Operation and Control (4 qtr. hrs.)

This course covers economic dispatch of thermal units and methods of solution; transmission system effects; generate with limited energy supply; production cost models; control of generation; interchange of power and energy; power system security; state estimation in power systems; optimal power flow. Prerequisite: ENGR 4540.

ENGR 4590 Power System Protection (4 qtr. hrs.)

This course covers methods of calculation of fault currents under different types of fault; circuit breakers, current transformers, potential transformers; basic principles of various types of relays; applications of relays in the protection of generator, transformer, line, and bus, etc. Prerequisite: ENGR 4540.

ENGR 4730 Introduction to Robotics (4 qtr. hrs.)

Introduction to the analysis, design, modeling and application of robotic manipulators. Review of the mathematical preliminaries required to support robot theory. Topics include forward kinematics, inverse kinematics, motion kinematics, trajectory control and planning, and kinetics. Applications include programming and task planning of a manufacturing robot manipulator. Prerequisites: ENME 2520 and MATH 2060 or MATH 2200 or instructor approval.

ENGR 4735 Linear Systems (4 qtr. hrs.)

This course focuses on linear system theory in time domain. It emphasizes linear and matrix algebra, numerical matrix algebra and computational issues in solving systems of linear algebraic equations, singular value decomposition, eigenvalue-eigenvector and least-squares problems, linear spaces and linear operator theory. It studies modeling and linearization of multi-input/multi-output dynamic physical systems, state-variable and transfer function matrices, analytical and numerical solutions of systems of differential and difference equations, structural properties of linear

dynamic physical systems, including controllability, observability and stability. It covers canonical realizations, linear state-variable feedback controller and asymptotic observer design, and the Kalman filter. Prerequisites: ENGR 3610, ENGR 3721/3722, or permission of the instructor.

ENGR 4740 Principles of Adaptive and Optimal Control Systems (4 qtr. hrs.)

This course covers fundamentals of adaptive and optimal control systems. Topics to be covered include: i) From adaptive control: parameter estimation, model reference adaptive systems, self-tuning regulators, gain scheduling, stability, alternatives to adaptive control; ii) From optimal control: principles and methods of optimal control, performance measures, dynamic programming, calculus of variations, Pontryagin's principle, variational approach to optimal control problems, optimal linear regulators with quadratic criteria, time and fuel optimal systems. Prerequisites: ENEE 3111, ENGR 3610, and ENGR 3721. Students must have knowledge of MATLAB.

ENGR 4745 Adv Non-Linear Control System (3 qtr. hrs.)

Limit cycles; functional analysis approach to input-output stability; analysis/synthesis of time-varying systems; feedback linearization, bang-bang control. Prerequisite: ENGR 3721

ENMT 3210 Mechatronics I (4 qtr. hrs.)

This course provides basic concepts from electrical, mechanical, and computer engineering as applied to mechatronic systems and is intended to serve as a foundation course for further exploration in the area of mechatronics. Prerequisite: senior or graduate standing in engineering.

ENMT 3220 Mechatronics II - Real-Time Systems (4 qtr. hrs.)

Real-time systems require timely response by a computer to external stimuli. This course examines the issues associated with deterministic performance including basic computer architecture, scheduling algorithms, and software design techniques including data flow diagrams, real-time data flow diagrams, stat transition diagrams, and petri nets. In the lab portion of this class, students program a microcontroller to interact with mechatronic devices. Prerequisite: ENMT 3210, ENCE 3210 or COMP 3354.

ENMT 4220 Mechatronics II (4 qtr. hrs.)

This course combines systems design and integration with a real world project involving the design and fabrication of an integrated system. Prerequisite: Mechatronics I or equivalent.

Prerequisite: ENEE 3111, ENCE 2101 or permission of instructor.

ENMT 4730 Advanced Ground Robotics (4 qtr. hrs.)

Intorduction to path planning and sensin and estimation for robotic manipulations and mobile robots. Review of the mathematical preliminaries required to support robot theory. Topics include advanced sensors, mobile robot mechanisms, advanced manipulator mechanisms, path planning in 2-D and 3-D, and simultaneous localization and mapping. Applications include task and motion planning for idealized and real robots. Prerequisite: ENGR 3730.

ENMT 4734 Unmanned Aerial Systems (4 qtr. hrs.)

Unmanned Aerial Vehicles (UAVs), or Unmanned Aircraft Systems (UAS) as is the preferred term by the US DOD, have seen unprecedented levels of growths in military and civilian application domains. Fixed-wing aircraft, heavier or lighter than air, rotary-wing (rotocraft, helicopters), vertical take-off and landing (VTOL) unmanned vehicles are being increasingly used in military and civilian domains for surveillance, reconnaissance, mapping, cartography, border patrol, inspection, homeland security, search and rescue, fire detection, agricultural imaging, traffic monitoring, to name just a few application domains. This course offers a very comprehensive study of UAS that includes: history of unmanned aviation, including evolution of designs and models for application-specific domains; modeling, control and navigation fundamentals for both teleoperation, semi-autonomous and fully autonomous flights; see-and-avoid-systems for different classes of UAS; integration of UAS into the National Airspace System (NAS); applications and case studies. Prerequisite: ENGR 3730.

ENCE 3231 Embedded Systems Programming (4 qtr. hrs.)

Design, construction and testing of microprocessor systems. Hardware limitations of the single-chip system. Includes micro-controllers, programming for small systems, interfacing, communications, validating hardware and software, microprogramming of controller chips, design methods and testing of embedded systems. Prerequisite: ENCE 3220.

ENCE 3321 Network Design (4 qtr. hrs.)

Introduction to network components. Layering of network architecture. Analysis of Local Area Network (LAN) concepts and architecture based on IEEE standards. Design principles including switching and multiplexing techniques, physical link, signal propagation, synchronization, framing and error control. Application of probability and statistics in error detecting and control. Ethernet, Token-ring, FDDI (Fiber Distributed Data Interface), ATM (Asynchronous Transfer Mode), ISDN (Integrated Service Data Networks).

ENEE 3670 Introduction to Digital Signal Processing (4 qtr. hrs.)

Introduction to the theory and applications of Digital Signal Processing. Special attention is paid to the fast Fourier transform and convolution and to the design and implementation of both FIR and IIR digital filters. Prerequisite: ENEE 3111.

ENGR 3610 Engineering Analysis (3 qtr. hrs.)

Applied mathematics for engineers. Generalized Fourier analysis, complex variables, vector calculus, introduction to Bessel functions, and applied probability and statistics. Prerequisites: MATH 2070, MATH 2080.

ENGR 3620 Advanced Engineering Mathematics (4 qtr. hrs.)

Applied mathematics for engineers. Systems and series solutions of ordinary differential equations, Fourier analysis, partial differential equations, linear algebra, vector calculus, special functions, unconstrained and combinatorial optimization, and applied probability and statistics. Prerequisites: MATH 2070 and MATH 2080.

ENGR 3630 Finite Element Methods (4 qtr. hrs.)

Introduction to the use of finite element methods in one or two dimensions with applications to solid and fluid mechanics, heat transfer and electromagnetic fields; projects in one or more of the above areas. Prerequisite: ENGR 3610 or equivalent.

ENGR 3721 Controls (3 or 4 qtr. hrs.)

Modeling, analysis and design of linear feedback control systems using Laplace transform methods. Techniques and methods used in linear mathematical models of mechanical, electrical, thermal and fluid systems are covered. Feedback control system models, design methods and performance criteria in both time and frequency domains. A linear feedback control system design project is required. Prerequisites: ENEE 2021, ENGR 3610 or permission of instructor.

ENGR 3722 Control Systems Laboratory (1 qtr. hrs.)

This laboratory course serves as supplement to ENGR 3721. It aims at providing "hands on" experience to students. It includes experiments on inverted pendulum, gyroscopes, motor control, feedback controller design, time-domain and frequency domain. Corequisite: ENGR 3721.

ENGR 3730 Robotics (3 qtr. hrs.)

Introduction to the analysis, design, modeling and application of robotic manipulators. Review of the mathematical preliminaries required to support robot theory. Topics include forward kinematics, inverse kinematics, motion kinematics, trajectory control and planning, and kinetics. Prerequisites: ENME 2520 and MATH 2060 or MATH 2200 or permission of instructor.

ENGR 3800 Topics (ENGR) (1 to 4 qtr. hrs.)

Special topics in engineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENGR 3900 Engineering Internship (1 to 4 qtr. hrs.)

Students in engineering may receive elective credit for engineering work performed for engineering employers with the approval of the chair or associate chair of the department. At the end of the term, a student report on the work is required, and a recommendation will be required from the employer before a grade is assigned. Junior, senior, or graduate status in engineering is normally required. May not be used to satisfy technical requirements. May be taken more than one for a maximum of 6 quarter hours. Prerequisite: permission of instructor.

ENGR 3951 Engineering Assessment II (0 qtr. hrs.)

Students in Mechanical Engineering must register for and take the Fundamentals of Engineering Examination (FE). All students must complete an engineering exit interview and other assessment related tasks. To be taken in the last quarter of attendance.

ENGR 4100 Instrumentation and Data Acquisition (4 qtr. hrs.)

ENGR 4620 Optimization (3 or 4 qtr. hrs.)

Engineering problems will be formulated as different programming problems to show the wide applicability and generality of optimization methods. The development, application, and computational aspects of various optimization techniques will be discussed with engineering examples. The application of nonlinear programming techniques will be emphasized. A design project will be assigned.

ENGR 4810 Advanced Topics (ENGR) (1 to 5 qtr. hrs.)

ENGR 4991 Independent Study (1 to 5 qtr. hrs.)

ENGR 4992 Directed Study (1 to 10 qtr. hrs.)

COURSE DESCRIPTIONS (Continued)

ENGR 4995 Independent Research (1 to 18 qtr. hrs.)

ENGR 5991 Independent Study (1 to 10 qtr. hrs.)

ENGR 5995 Independent Research (1 to 18 qtr. hrs.)