

A Proposal for a

MASTER OF SCIENCE DEGREE IN ROBOTICS



Marlan and Rosemary Bourns College of Engineering

University of California – Riverside

Riverside, CA 92521

Submitted by

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M.S. Robotics Approvals

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SECTION 1: INTRODUCTION

This document is a proposal for a Master of Science (M.S.) degree in Robotics, which will be jointly managed by the departments of Computer Science and Engineering (CSE), Electrical and Computer Engineering (ECE), and Mechanical Engineering (ME). Degree requirements and administration of the program are described in this document.

1.1. Program Objectives

The objective of the MS in Robotics program will be to provide inter-disciplinary training in various aspects that are involved in the design, construction, and deployment of robots and autonomous systems. Students will gain exposure to the foundational principles underlying mechanical and electronic aspects of robot design, control and navigation of robots, and artificial intelligence required for robots to perceive their surroundings and make decisions.

The program will admit students from various backgrounds with undergraduate training that is very diverse. The committee overseeing the formation of the program has considered this aspect very carefully, and designed a program that provides both breadth and depth. Students will be exposed to the breadth of the area through a set of core courses spanning all three departments, but will then be able to focus on a single aspect of robotics (e.g., mechanical design or machine learning) to gain in-depth knowledge.

1.2. Historical Development

Robotics deals with the design and operation of robots, which includes mechanical, electronic and computer design, as well as software systems that are capable of processing sensory inputs, reasoning about the operational environment, and making decisions about future operations. It is an area of very fast-growing interest driven by the recent advances in artificial intelligence research and technology development. Application areas are varied including manufacturing, logistics, health care, public safety, and the military.

At UCR, relevant sub-areas of robotics have been offered in the three departments. For example, ME offers courses in robot design and controls, ECE in controls and machine learning, computer engineering (CEN) (joint program between ECE and CSE) in real-time system design, and CSE in machine learning and data mining. The courses are regularly offered and are, in fact, very popular. However, we do not have a program structure that allows students access to a curriculum that will provide a holistic understanding of robotics.

The proposed program will allow students with undergraduate degrees from the above-mentioned departments to enroll in a masters level program in robotics that will allow them to gain a holistic understanding of the subject, while focusing on parts of it for a deeper understanding depending upon their interests. It will rely on existing faculty and courses within these departments.

The proposed program will be built mostly on existing courses (only a couple of new courses will be added) and leverage upon existing facilities in the three departments. Future course offerings will also be through the three departments. The faculty affiliated with the program will be from the three departments.

1.3 Enrollment Projections

There has been a concerted effort in BCoE to increase our MS enrollment. For Fall 2019, the expected number of MS students in CS is 170, CEN 68, EE 59, and ME 20. The Robotics MS program is expected to be at least as much in demand as the EE and CEN programs. We expect to start at about 20 students in the first two years as the information about the program is disseminated. Within 5 years, we expect it to be about 50 students in the program. This would be achieved without hurting enrollment in the CS, ME, CEN, or EE programs, thus driving up overall enrollment in BCoE. We also expect that many of these students will stay on for PhDs, thus allowing us to select PhD students who have already been at UCR.

1.4 Justification for MS in Robotics Program

Automation is today an aspect of everyday life, and is expected to increase further. Some of the most exciting technological problems, with the potential for large-scale societal impact, are related to automation. Some categories include transportation, health care, logistics, and public safety. At the US National Science Foundation (NSF), robotics is a major part of multiple programs, including Emerging Frontiers in Research and Innovation which focused on soft robotics, the National Robotics Initiative and Cyber-Physical Systems program. In fact, robotics is a core part of many of the initiative in [NSF's 10 Big Ideas](#). These include:

- Future of Work at the Human-Technology Frontier, which aims to understand and build the human-technology relationship,
- Growing Convergence Research, where robotics could be used for improving human health or understanding the food, energy, water nexus,
- Harnessing the Data Revolution, which will enable robots to understand and reason about their environment, and
- Navigating the New Arctic, where robotic technology can be critical to map and navigate in remote areas.

Robotics, including manipulation, human-robot interaction, intelligence and perception are critical parts of many Department of Defense research programs. In fact, the DoD plans to invest over \$2 billion over the next five years in artificial intelligence research, which encompasses many aspects of robotics.

Robotics is a program in many universities at both the undergraduate and graduate levels, and many new ones are being developed. For example, CMU has had a [robotics program](#) for many years housed within their Robotics Institute. Arizona State has a [masters degree in robotics](#) across mechanical engineering, electrical engineering, computer engineering and computer science. UPenn has a similar [masters degree program](#) in robotics, as does [Northwestern University](#). In addition, many other universities offer robotics as a specialization within their programs in either the mechanical, electrical or computer science departments.

Jobs in robotics fall within two broad categories: a) mechanical robot design, attracting mostly students with an ME background, and b) computer and information sciences, attracting mostly students with ECE and CS backgrounds. According to the Bureau of Labor Statistics, both are projected to grow rapidly over the next decade. Growth in mechanical engineering jobs is expected to be about 9% and growth in computer and information science jobs is expected to be about 19% from 2016-2026.

A Masters degree in engineering provides many long-term benefits. According to the National Research Council, “data from the National Science Foundation (NSF) reveal that median salaries of master’s degree recipients one to five years after the degree was conferred tend to be higher than those of doctorates. More importantly, salaries of master’s degree holders in science and engineering have grown faster over the past 10 years than salaries of baccalaureate or doctorate holders.” Coupled with the projected growth in jobs in robotics and autonomous systems, it should be expected that a MS in robotics would be an extremely popular program among students with undergraduate degrees in ME, EE, CEN and CS. We also expect students with backgrounds in physics or mathematics to be able to enroll in the program.

1.5 Contributions to Diversity

Recruitment: UCR is an accredited Hispanic Serving Institution (OPEID 00131600), with approximately 35% Hispanic enrollment. BCOE has a much higher proportion of undergraduates from underrepresented backgrounds compared to Engineering Schools at comparably-ranked R1 universities in the US. Prior research has established that the hands-on aspects of robotics, coupled with clear workforce-related applications of the technology, appeal to students from underrepresented backgrounds and increase engagement, involvement, and retention [1-3]. The MS Robotics program aims to recruit from the four closely related BS programs—ME, EE, CEN, and CS. The fast-growing nature of the field of robotics (and AI in general) is a great motivating factor for these students to complete a cross-disciplinary MS degree before entering the workforce. In addition to BCOE, the MS Robotics program will recruit from other local HSIs, such as California State University campuses in the Southern California region (e.g., San Bernardino, Cal Poly Pomona, etc.).

Curriculum and pedagogy: The cross-disciplinary nature of robotics creates the opportunity to build curriculum that is sensitive to the needs of diverse learners as well as diverse members of society. Of particular interest and concern is the subject of algorithmic bias in AI and machine learning. The design of AI systems has been primarily the domain of white, male engineers [4], and several scholars have suggested that efforts toward inclusion in the ranks of those who design AI systems could reduce bias [5, 6]. For example, just 12% of machine learning engineers are women [7], with Black AI leaders pointing to a “diversity crisis” in the field [8]. Critiques of simple inclusivity efforts suggest that diversity programs cannot address overlapping forms of inequality, and have called for applying a more deliberate lens of intersectionality to the algorithm design [9, 10]. To this end, the MS Robotics program will work closely with the CS and ECE Departments to update their AI, machine learning, and computer vision graduate-level curricula to address algorithmic bias, including how biased vs. unbiased robots may impact society as the technology evolves.

Outreach: Students in the MS Robotics program will be encouraged to participate with ongoing efforts at UCR to provide mentorship and broaden participation in robotics-related activities. One recent example is UCR's K-12 Lego Robotics Competition [11]. BCOE student organizations such as the IEEE@UCR (affiliated with the ECE Department) have a long and successful history of outreach efforts to the local community which bring K-12 students to campus. The MS Robotics program will work with BCOE student organizations to create new opportunities for graduate student leadership and participation surrounding community outreach events.

[1] H. Yi, "Robotics and kinetic design for underrepresented minority (URM) students in building education: Challenges and opportunities", *Comput Appl Eng Educ.* 2019; 27:351–370.

[2] R.A. Pitt, "Impact of an Updated Robotics Laboratory in an Industrial Engineering Program" 2012 ASEE ANNUAL CONFERENCE retrieved from <https://www.asee.org/public/conferences/8/papers/5066/download>

[3] V.V. Morris, R.A. Stein, J.F. Keller, and V. Kumar, "Robotics in Urban STEM Education: The Philadelphia Model" 2011 ASEE ANNUAL CONFERENCE retrieved from https://www.asee.org/file_server/papers/attachment/file/0001/1962/Robotics_In_Urban_STEM_Education-The_Philadelphia_Model.pdf

[4] Crawford, Kate (2016-06-25). "Opinion | Artificial Intelligence's White Guy Problem". *The New York Times*. ISSN 0362-4331. Retrieved 2020-02-11.

[5] Jobin, Anna; Ienca, Marcello; Vayena, Effy (2 September 2019). "The global landscape of AI ethics guidelines". *Nature Machine Intelligence*. 1 (9): 389-399. arXiv:1906.11668. doi:10.1038/s42256-019-0088-2.

[6] "White Paper: How to Prevent Discriminatory Outcomes in Machine Learning". *World Economic Forum*. 12 March 2018. Retrieved 11 February 2020.

[7] "AI Is the Future—But Where Are the Women?". *Wired*. ISSN 1059-1028. Retrieved 2020-02-11.

[8] Snow, Jackie. "'We're in a diversity crisis': cofounder of Black in AI on what's poisoning algorithms in our lives". *MIT Technology Review*. Retrieved 2020-02-11.

[9] Ciston, Sarah (2019-12-29). "Intersectional AI Is Essential". *Journal of Science and Technology of the Arts*. 11 (2): 3–8. doi:10.7559/citarj.v11i2.665. ISSN 2183-0088.

[10] D'Ignazio, Catherine; Klein, Lauren F. (2020). *Data feminism*. MIT Press. ISBN 0262044005.

[11] FIRST LEGO League, www.firstlegoleague.org. UCR has hosted the regional competition in recent years.

1.6 Relation to Other Programs in the UC System

There is no MS in Robotics program within the UC system. However, robotics, or aspects of it, are part of existing EE, CEN, CS or ME programs. They are focused on sub-parts of robotics, e.g., robot design, robot control, or robot perception and learning. Our program will provide a broad exposure to these sub-areas, while allowing for students to focus on one of them.

1.7 Administration of the Program

The program will be led by a Program Director, assisted by an Associate Director. While the Director will focus on the overall program and coordination among the departments, the Associate Director will serve the role of Graduate Advisor taking care of all graduate student advising issues within the program. A staff will help the faculty Directors in administering the program. The Program Director will rotate among the 3 departments. The Associate Director will be from a different department than the Director and this position will also rotate among the departments.

The faculty in the program will be comprised of Senate faculty in related research areas from the three departments. As robotics is a very broad area, a large number of faculty from all three associated departments will have interests that relate to robotics. In the interest of efficient administration, a core group of faculty will be appointed to oversee the program and coordinate efforts with the departments. This Oversight Committee will be led by the Director and Associate Director and comprise faculty from all three departments. The committee will have an equitable distribution of faculty from the three departments and the different technical areas of interest to the program.

This initial proposal was created by the following group of faculty. An oversight committee will be created from senior faculty from this committee, or other senior faculty from the affiliated departments.

Jiasi Chen (CSE)
Konstantinos Karydis (ECE)
Hyoseung Kim (ECE)
Amit Roy Chowdhury (ECE) - Committee Chair
Christian Shelton (CSE)
Fabio Pasqualetti (ME)
Luat Vuong (ME)

The list of all faculty involved with interests that are aligned to different aspects of robotics (see program description in Sec. II) is listed later.

1.8 Evaluation of the Program

As is the norm for all graduate programs at the UCR campus, an outside team of experts will evaluate the program once every six or seven years. Beginning with the second year, the Program Committee will initiate an internal review of the M.S. Robotics Program.

SECTION II: PROGRAM

The MS Robotics program will be built using existing courses, with a couple of new courses. Below we describe the structure of the program and then the admission requirement.

2.1 Robotics MS Program

The MS in Robotics requires the completion of 40 units of coursework, including possibly, a project. Units are divided among core courses (5 courses, for a total of 20 units), focus courses (3 courses, for a total of 12 units), and elective courses (2 courses or 1 project, for a total of 8 units). All students must complete the same core courses. Focus courses must belong to the same focus area, which is selected by the student among four possible choices. At most 1 focus course can be at the undergraduate level, from the approved list in each focus area. Elective courses are selected by the student within a list of possible courses, can be at the undergraduate level, and can be substituted with a supervised research project. A total of 12 units maximum can be at the undergraduate level, selected from the list of courses below.

Core courses:

- | | |
|---|-------------|
| 1. Computational methods for robotics | ME204 |
| 2. Design and fabrication of robots | ME 205 |
| 3. Linear control systems | EE 235 |
| 4. Advanced robotics | EE 245 |
| 5. Machine Learning/Pattern Recognition | CS229/EE240 |

Focus Area courses:

- 1) Mechanical design and fabrication
ME 174, ME 175B, ME 175C, ME 210, ME 230, ME 232, ME 233, ME 271
- 2) Embedded platforms and system design
EE 217, EE 246, EE 255, EE 258
CS 171, CS 256
- 3) Control and navigation
ME 121, ME 145, ME 220, ME 223
EE 132, EE 144, EE 151, EE 231, EE 236, EE 237, EE 238, EE 239, EE 246
- 4) Artificial intelligence and perception
ME 202, ME 233
EE 142, EE 146, EE 236, EE 241, EE 243, EE244, EE 247
CS 170, CS 171, CS 173, CS 205, CS 227, CS 235

Elective courses:

1. Any course in the focus areas, as long as it is not used to meet the Focus Area requirements.
2. ME 114, ME 118, ME 120, ME 130, ME 133, ME 153, ME 176, ME 200, ME 201, ME 203, ME 210, ME 231, ME 233, ME 270, ME 274
3. Any course listed in the EE Graduate Manual in the areas Signals, Systems and Machine Intelligence (SSMI) and VLSI Circuits and Systems (VCS). Undergrad courses in the

following undergrad EE focus areas are allowed: Communications, Signal Processing and Networking; Controls, Robotics and Machine Intelligence; and VLSI and Embedded Systems.

4. Any graduate CS course listed in the Catalog under the CS Graduate Program in the Major Specialty Areas of C (Databases, Information Retrieval, Data Mining, and Machine Learning), D (Operating Systems, Distributed Systems, and High Performance Computing), or E (Computer Networks). Undergraduate CS courses CS170, CS 171, CS 172, CS 173 are also allowed.
5. For the following pairs of courses, only one can be taken for credit in the program: (EE142, CS171), (ME121, EE132), (CS229, EE240)
6. Any other courses will require approval of the program graduate advisor.

The description of all the courses is available later in the proposal. Rather than listing all courses, we purposely mention all courses in certain areas of ECE, ME, and CSE departments. These areas are relevant to robotics, and as the courses in these areas evolve, they should be available to students in the robotics program.

Capstone Experience:

Students must complete a capstone experience that integrates knowledge from across their course of study by selecting one of the two options below.

Comprehensive Exam Options:

Students will need to take a comprehensive exam based on the courses in the program. The faculty committee overseeing the program will coordinate with the individual departments on the logistics of exam.

Project Option:

Students must complete a research project under the guidance of a faculty member. The project will be approved by a committee of at least two faculty members and requires a presentation and written report.

Normative Time to Degree: Six quarters (two years)

Professional Development:

All MS Robotics students must enroll in a colloquium series every quarter of their study. The program oversight committee will coordinate with the three departments – ME, ECE and CSE – to identify the set of colloquia that the students should attend. Each department has its own colloquium series; the inter-departmental nature of the Robotics program calls for students attending colloquia in multiple departments.

Additionally, students in the program must submit a Professional Development Report that details the students' efforts in developing their technical writing and presentation skills. This report should be submitted to and approved by the program Oversight Committee, as part of the Capstone experience. Specific guidance for this report will be provided by the committee to the students.

2.2 Admission Requirements

All applicants to this program must have completed a Bachelor’s degree or its approved equivalent from an accredited institution and to have attained undergraduate record that satisfies the standards established by the Graduate Division and University Graduate Council. Applicants should have at least an undergraduate major in Mechanical Engineering, Computer Engineering, Computer Science, Electrical Engineering or a closely related field. Applicants who fail to meet this criterion may sometimes be admitted with course deficiencies, provided they take remedial steps to cover the deficiencies.

A student who is deficient in a competency area may be asked to complete the corresponding UCR course with a letter grade of at least B, or to pass a challenge examination based on that course’s final exam with a grade of at least B. All such remedial work should be completed within the first year of graduate study, and in all cases the deficiency(s) must be corrected BEFORE a student can enroll in any graduate course from the same specialty area. The details will be decided by the Graduate Advisor of the program in consultation with the student.

All applicants must submit scores from the Graduate Record Exam, General Test (GRE). Relevant GRE subject tests may be beneficial to the candidate’s application, but are not required. Applicants whose first language is not English are required to submit acceptable scores from the TEST of English as a Foreign Language (TOEFL) or the International English Language Testing System (IELTS) unless they have a degree from an institution where English is the exclusive language of instruction. Additionally each applicant must submit letters of recommendation, as per the admission requirements. All other application requirements are specified in the graduate application.

The committee designing the program fully recognizes that students from ME, EE, CEN and CS have different undergraduate training. The program is designed so that all students who have completed their undergraduate degrees in these areas will be able to take these courses. The program also allows for a number of undergrad courses which can be taken to build the fundamentals necessary before the graduate course is taken.

2.3 Sample Program

Since the MS Robotics program will have students from different backgrounds, there are multiple sample programs. Note that the courses are also being taken by MS and PhD students in ME, EE, CEN and CS programs, so many of them are offered multiple times a year. Also, given the variety of focus areas and electives possible and because students will need to concentrate on one of the focus areas (FAs), the sample plan is written in generic terms, rather than specific courses.

Sample Program for MS Robotics students

	Fall	Winter	Spring
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Year 1	ME204 EE235 Elective from FA1	ME205 EE245 CS229/EE240	FA courses and electives
Year 2	FA courses and electives		

SECTION III: PROJECTED NEEDS

3.1 Student Demand and Opportunities

The numbers of students in the BS and MS programs in EE, CEN, CS and ME are increasing rapidly. There is also tremendous interest from industry in the areas of robotics and AI. Many students in the various undergraduate clubs have expressed interest in a robotics program. While we have most of the courses, the structures of the existing programs do not allow them to take the proper set of courses required for specialized training in robotics.

This demand is directly related opportunities for students after graduation. As reflected in our Focus Areas, students will have the opportunity to concentrate on different aspects of robotics ranging from fabrication, to electronic design, to control and navigation, to machine learning and perception. They are different components of artificial intelligent systems, where there is tremendous demand in the private sector, as well as for further graduate studies should the students wish to.

3.2 Relation to Research and Faculty Interests

As described above, almost all the courses for the program already exist at UCR. Thus, these areas are already of high interest to faculty. They are also well funded with research areas. The number of PhD students across the three departments working in research topics that fall within one of the FAs is about 100.

SECTION IV: FACULTY AND STAFF

As mentioned earlier, robotics is a very broad and a large number of faculty are associated with related topics. Below, we list faculty in the three departments who regularly teach courses and conduct research on relevant topics. We also mention the Focus Area that the faculty is most closely related to under Research Interests. Faculty in the program will be expected to be involved with research and teaching activities in at least one of the main focus areas of the program. The program will be supported by a staff member from within one of the departments.

Mechanical Engineering

Fabio Pasqualetti

Associate Professor, Department of Mechanical Engineering
Ph.D. Mechanical Engineering, University of California - Santa Barbara, 2012
Research Interests: Control and navigation

Luat Vuong

Assistant Professor, Department of Mechanical Engineering
Ph.D. Applied Physics, Cornell University, 2008
Research Interests: Control and navigation

Jun Sheng

Assistant Professor, Department of Mechanical Engineering
Ph.D Robotics, Georgia Institute of Technology, 2019
Research Interests: Mechanical Design and Fabrication

Sundararajan Venkatadriagaram

Associate Professor of Teaching, Dept. of Mechanical Engineering
Ph.D. UC Berkeley, 2000
Research Interests: Mechanical Design and Fabrication

Erfan Nosari

Assistant Professor, Department of Mechanical Engineering
Ph.D. Mechanical and Aerospace Engineering, UC San Diego, 2019
Research Interests: Control

Electrical and Computer Engineering

Salman Asif

Assistant Professor, Department of Electrical and Computer Engineering
Ph.D. Electrical and Computer Engineering, Georgia Institute of Technology, 2013
Research Interests: Artificial intelligence and perception

Matt Barth

Professor, Department of Electrical and Computer Engineering
Ph.D. Electrical and Computer Engineering, University of California, Santa Barbara, 1990
Research Interests: Control and navigation

Bir Bhanu

Professor, Department of Electrical and Computer Engineering
Ph. D. Electrical Engineering, University of Southern California, 1981
Research Interests: Artificial intelligence and perception

Jay Farrell

Professor, Department of Electrical and Computer Engineering
Ph.D. Electrical Engineering, University of Notre Dame, 1989
Research Interests: Control and navigation

Konstantinos Karydis

Assistant Professor, Department of Electrical and Computer Engineering
Ph.D Mechanical Engineering, University of Delaware, 2015
Research Interests: Control and navigation

Hyoseung Kim

Assistant Professor, Department of Electrical and Computer Engineering
Ph.D Electrical and Computer Engineering, Carnegie Mellon University, 2016
Research Interests: Embedded platforms and system design

Wei Ren

Professor, Department of Electrical and Computer Engineering
Ph.D. Electrical Engineering, Brigham Young University, 2004
Research Interests: Control and navigation

Samet Oymak

Assistant Professor
Ph.D. Electrical Engineering, Caltech 2015
Research Interests: Artificial intelligence and perception

Amit K. Roy-Chowdhury

Professor, Department of Electrical and Computer Engineering
Ph.D. Electrical Engineering, University of Maryland - College Park, 2002
Research Interests: Artificial intelligence and perception

Computer Science and Engineering

Nael Abu-Ghazaleh

Professor, Department of Computer Science and Engineering and Electrical and Computer Engineering (joint appointment)

Ph.D. Computer Engineering, University of Cincinnati, 1997

Research Interests: Embedded platforms and system design

Philip L. Brisk

Associate Professor, Department of Computer Science and Engineering

Ph.D. Computer Science, University of California - Los Angeles, 2006

Research Interests: Embedded platforms and system design

Jiasi Chen

Assistant Professor, Department of Computer Science and Engineering

Ph.D. Electrical Engineering, Princeton University, 2015

Research Interests: Artificial intelligence and perception

Eamonn Keogh

Professor, Department of Computer Science and Engineering

Ph.D. Computer Science, University of California - Irvine, 2001

Research Interests: Artificial intelligence and perception

Evangelos Papalexakis

Assistant Professor, Department of Computer Science and Engineering

Ph.D. Computer Science, Carnegie Mellon University, 2016

Research Interests: Artificial intelligence and perception

Christian Shelton

Professor, Department of Computer Science and Engineering

Ph.D. Computer Engineering, Massachusetts Institute of Technology, 2001

Research Interests: Artificial intelligence and perception

SECTION V: COURSES

In this section, we list all the courses that are part of the program.

1. Core Courses

1. CS 229 - Machine Learning
2. EE 235 - Linear System Theory
3. EE 245 - Advanced Robotics
4. ME 204 - Computational Methods for Robotics
5. ME 205 - Design and Fabrication of Robots

CS 229. *Machine Learning* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 100, STAT 155. CS 229 online section; enrollment in the Online Master-in-Science in Engineering program. A study of supervised machine learning that emphasizes discriminative methods. Covers the areas of regression and classification. Topics include linear methods, instance-based learning, neural networks, kernel machines, and additive models. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 235. *Linear System Theory* (4) Lecture, 3 hours, discussion, 1 hour. Prerequisite(s): EE 132. Provides a review of linear algebra. Topics include the mathematical description of linear systems; the solution of state-space equations; controllability and observability; canonical and minimal realization; and state feedback, pole placement, observer design, and compensator design. Cross-listed with ME 235.

EE 245. *Advanced Robotics* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 236/ME 236; ME 120 or equivalent. Topics include robot navigation; description of robot sensors and their characteristics; sensor data processing; feature extraction; and matching. Also covers representations of space for mapping; map based localization; simultaneous localization and mapping; image-based motion estimation; and motion planning. Cross-listed with ME 222.

ME 204. *Computational Methods for Robotics* (4) Lecture 3 hours. Laboratory 3 hours. Lecture: 3 hours. Laboratory: 3 hours. This course provides the students with basic and advanced knowledge of linear algebra, numerical methods, and computational tools, and is foundational for a multidisciplinary curriculum comprising courses in controls, robotics, signal processing, and machine intelligence. Topics include matrix theory, linear algebra and vector spaces, singular value decomposition and matrix approximation, numerical methods for, for instance, integration, differentiation, and solution of linear and nonlinear equations, least-squares and least-norm problems, and optimization problems and methods for their solution. Hands-on lab exercises will be drawn from different application domains, and will provide familiarity with commonly used computational tools.

Approval for ME 204 has been submitted separately. Changes to the course description during its approval process will be reflected also in this document.

ME 205. *Design and Fabrication of Robots* (4) Lecture 3 hours. Laboratory 3 hours. The design and fabrication of robots require the interdisciplinary integration of mechanical systems, electrical systems, control systems, and computers to develop high-performance machines. This course reviews traditional precision machine design, electromagnetic driving systems, and

integration principles. It also presents the state-of-the-art actuators, sensors, transmissions, and fabrication methods with their applications to modern robotic systems. Hands-on lab exercises and design projects provide extensive training in the modeling, design, and fabrication of individual mechatronic components as well as complete robotic systems.

Approval for ME 205 has been submitted separately. Changes to the course description during its approval process will be reflected also in this document.

2. Focus Areas

Focus Area 1. Mechanical Design and Fabrication:

- ME 174 - Machine Design
- ME 175B - Mechanical Engineering Design
- ME 175C - Mechanical Engineering Design
- ME 210 - Sustainable Product Design
- ME 230 - Computer-Aided Engineering Design
- ME 232 - Computational Design Tools
- ME 233 - Artificial Intelligence for Design
- ME 271 - Nanoscale Science and Engineering

ME 174. *Machine Design* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): ME 009, ME 103 (can be taken concurrently), ME 110, ME 114. An introduction to the fundamentals of strength-based design. Topics include deflection and stiffness, static failure, and fatigue failure.

ME 175B. *Mechanical Engineering Design* (3) Lecture, 2 hours; laboratory, 3 hours. Prerequisite(s): senior standing in Mechanical Engineering. ME 113, ME 116A, ME 170A, ME 174, ME 175A (may be taken concurrently). Outlines the defining of a design problem and the conception and detail of the design solution. Explores design theory, design for safety, reliability, manufacture, and assembly. Graded In Progress (IP) until ME 175B and ME 175C are completed, at which time a final, letter grade is assigned.

ME 175C. *Mechanical Engineering Design* (3) Lecture, 1 hour; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): senior standing in Mechanical Engineering; ME 175B. Students create, test, and evaluate a prototype based on the project design generated in ME 175B. Lecture topics include prototyping techniques, design verification, and special topics in design. Satisfactory (S) or No Credit (NC) grading is not available.

ME 210. *Sustainable Product Design* (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): graduate standing or consent of instructor. ME 210 online section; enrollment in the Online Master-in-Science in Engineering program. Introduces the principles of sustainable product design. Topics include life cycle design; design for reliability, maintainability, and recycling/reuse/remanufacture; materials selection; and manufacturing processes. Includes project in which students analyze the environmental impact of a product and redesign it to reduce the impact. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Credit is awarded for only one of ME 176 or ME 210.

ME 230. *Computer-Aided Engineering Design* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): graduate standing or consent of instructor. ME 230 online section; enrollment in the Online Master-in-Science in Engineering program. Introduces fundamentals of interactive computer graphics, three-dimensional representations of curves and surfaces, Bezier parameterizations, and optimization methods. Demonstrates applications of computer graphics and computational geometry to mechanical system simulations, computer-aided design, and engineering design.

ME 232. *Computational Design Tools* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. An introduction to the theoretical foundations and practical application of computational techniques for engineering design. Topics include geometric modeling, numerical optimization, and artificial intelligence techniques. Includes programming projects in which both symbolic and numerical computational techniques are used to solve engineering problems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

ME 233. *Artificial Intelligence for Design* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Explores the application of artificial intelligence to engineering design. Topics include the use of search, knowledge-based systems, machine learning, and qualitative physical reasoning for design automation. Addresses the theory behind these techniques and issues related to their practical application. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable as content changes.

ME 271. *Therapeutic Biomedical Microdevices* (4) Lecture, 4 hours. Prerequisite(s): ME 270/MSE 238 or equivalent or consent of instructor. An introduction to the application of micro device technology towards biomedical therapeutics. Topics include emerging micro device fabrication techniques, bio compatibility requirements, and applications in areas such as cardiovascular intervention, minimally-invasive drug delivery, neuroprosthetic interfaces, and cellular engineering. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

Focus Area 2. Embedded Platforms and System Design:

- EE 217 - GPU Architecture and Parallel Programming
- EE 246 - Intelligent Transportation Systems
- EE 255 - Real-Time Embedded Systems
- EE 258 - Modeling and Synthesis of Cyber-Physical Systems
- CS 171 - Introduction to Machine Learning and Data Mining
- CS 256 - Modeling and Synthesis of Cyber-Physical Systems

EE 217. *GPU Architecture and Parallel Programming* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 160 with a grade of “C-” or better or consent of instructor. Introduces the popular CUDA based parallel programming environments based on Nvidia GPUs. Covers the basic CUDA memory/ threading models. Also covers the common data-parallel programming patterns needed to develop a high-performance parallel computing applications. Examines computational thinking; a broader range of parallel execution models; and parallel programming

principles. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. May be taken Satisfactory (S) or No Credit (NC) by students advanced to candidacy for the Ph.D. Cross-listed with CS 217.

EE 246. *Intelligent Transportation Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. EE 115 and EE 132 are recommended. Focuses on the control, communications, and computer aspects of intelligent transportation systems. Topics include traffic flow theory fundamentals, intelligent transportation system user services, travel and traffic management, advanced vehicle safety systems, intelligent transportation system applications, architectures, standards, strategic needs assessment and deployment, and evaluation.

EE 255. *Real-Time Embedded Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 120B/CS 120B, or equivalent; consent of instructor. Covers the fundamentals and principles of real-time embedded systems. Topics include uniprocessor and multiprocessor real-time scheduling, real-time operating systems, synchronization, resource reservation, memory management, power management, etc. Introduces mathematical techniques for real-time system analysis. Offers hands-on experience with designing, implementing, and evaluating real-time systems on embedded platforms. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 258. *Modeling and Synthesis of Cyber Physical Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Introduces trends and challenges of modern cyber-physical systems. Reviews state-of-the-art design approaches and tools in both academia and industry. Introduces fundamental concepts in functional modeling, real-time embedded architecture, design synthesis and validation. Introduces emerging design principles and their applications in automotive, avionics, smart buildings, and consumer electronics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with CS 256.

CS 171. *Introduction to Machine Learning and Data Mining* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 100, MATH 010A or MATH 031. Introduces formalisms and methods in data mining and machine learning. Topics include data representation, supervised learning, and classification. Covers regression and clustering. Also covers rule learning, function approximation, and margin-based methods.

CS 256. *Modeling and Synthesis of Cyber Physical Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Introduces trends and challenges of modern cyber-physical systems. Reviews state-of-the-art design approaches and tools in both academia and industry. Introduces fundamental concepts in functional modeling, real-time embedded architecture, design synthesis and validation. Introduces emerging design principles and their application in automotive, avionics, smart buildings, and consumer electronics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with EE 258.

Focus Area 3. Control and Navigation:

- ME 121 - Feedback Control
- ME 145 - Robotic Planning and Kinematic
- ME 220 - Optimal Control and Estimation
- ME 223 - Secure and Reliable Control Systems
- EE 132 - Automatic Control
- EE 144 - Introduction to Robotics
- EE 151 - Introduction to Digital Control
- EE 231 - Convex Optimization in Engineering Applications
- EE 236 - State and Parameter Estimation Theory
- EE 237 - Nonlinear Systems and Control
- EE 238 - Linear Multivariable Control
- EE 239 - Optimal Control
- EE 246 - Intelligent Transportation Systems

ME 121. *Feedback Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): ME 118, ME 120. Introduces students to the analysis and design of feedback control systems using classical control methods. Topics include control system terminology, block diagrams analysis and design of control systems in the time and frequency domains, closed-loop stability, root locus, Bode plots, and an introduction to analysis in state-space.

ME 145. *Robotic Planning and Kinematics* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): ME 120 or equivalent; or consent of instructor. Motion planning and kinematics topics with an emphasis in geometric reasoning, programming, and matrix computations. Motion planning includes configuration spaces, sensor based planning, decomposition and sampling methods, and advanced planning algorithms. Kinematics includes reference frames, rotations and displacements, and kinematic motion models. Cross-listed with EE 145.

ME 220. *Optimal Control and Estimation* (4) Lecture, 4 hours; term paper, 1 hour. Prerequisite(s): ME 120, ME 121 or equivalent; or consent of instructor. Introduces optimal control and estimation with specific focus on discrete time linear systems. Topics include analysis of discrete Riccati equations; asymptotic properties of optimal controllers; optimal tracking; an introduction to Receding Horizon control; derivation of the Kalman filter; Extended Kalman Filter; and Unscented Kalman filter. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with EE 233.

ME 223. *Secure and Reliable Control Systems* (4) Lecture, 4 hours. Prerequisite(s): graduate standing or consent of instructor. ME 223 online section; enrollment in the Online Master-in Science in Engineering program. An introductory study of fault-tolerant and secure control systems. Topics include models of dynamical systems; linear system theory; detectability of attacks and failures; model-based fault detection; analytical redundancy; unknown-input observers; statistical methods for fault detection; graphical models and structured system theory; and fault-tolerant control. Letter Grade or S/NC; no petition required.

EE 132. *Automatic Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 105 or ME 103 or equivalent; EE 110A or ENGR 118; or consent of instructor. Covers mathematical

modeling of linear systems for time and frequency domain analysis. Topics include transfer function and state variable representations for analyzing stability, controllability, and observability; and closed-loop control design techniques by Bode, Nyquist, and root-locus methods. Laboratories involve both simulation and hardware exercises.

EE 144. *Introduction to Robotics* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 132. Covers basic robot components from encoders to microprocessors. Kinematic and dynamic analysis of manipulators. Addresses open- and closed-loop control strategies, task planning, contact and noncontact sensors, robotic image understanding, and robotic programming languages. Experiments and projects include robot arm programming, robot vision, and mobile robots. Cross-listed with ME 144.

EE 151. *Introduction to Digital Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 132, EE 141. Review of continuous-time control systems; review of Z-transform and properties; sampled-data systems; stability analysis and criteria; frequency domain analysis and design; transient and steady-state response; state-space techniques; controllability and observability; pole placement; observer design; Lyapunov stability analysis. Laboratory experiments complementary to these topics include simulations and hardware design.

EE 231. *Convex Optimization in Engineering Applications* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): EE 230. Covers recognizing and solving convex optimization problems that arise in engineering applications. Explores convex sets, functions, and optimization problems. Includes basics of convex analysis, least-squares, linear and quadratic programs, semidefinite programming, minimax, and other problems. Addresses optimality conditions, duality theory, theorems of alternative and applications, interior-point methods, and applications in engineering.

EE 236. *State and Parameter Estimation Theory* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215. Covers autoregressive and moving-average models; state estimation and parameter identification (including least square and maximum likelihood formulations); observability theory; synthesis of optimum inputs; Kalman-prediction (filtering and smoothing); steady-state and frequency domain analysis; online estimation; colored noise; and nonlinear filtering algorithms. Cross-listed with ME 236.

EE 237. *Nonlinear Systems and Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 235/ME 235. Explores nonlinear systems and control. Topics include nonlinear differential equations, second order nonlinear systems, equilibrium and phase portrait, limit cycle, harmonic analysis and describing function, Lyapunov stability theory, absolute stability, Popov and circle criterion, input-output stability, small gain theorem, averaging methods, and feedback linearization. Cross-listed with ME 237.

EE 238. *Linear Multivariable Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 235/ME 235. Investigates multivariable feedback systems, stability, performance, uncertainty, and robustness. Topics include analysis and synthesis via matrix factorization; Q-parameterization and all stabilizing controllers; frequency domain methods; and H(insert

infinity) design and structured singular value analysis. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with ME 238.

EE 239. *Optimal Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215, EE 235/ME 235. Presents the theory of stochastic optimal control systems and methods for their design and analysis. Covers principles of optimization; Lagrange's equation; linear-quadratic-Gaussian control; certainty-equivalence; the minimum principle; the Hamilton-Jacobi-Bellman equation; and the algebraic Riccati equation. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with ME 239.

EE 246. *Intelligent Transportation Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. EE 115 and EE 132 are recommended. Focuses on the control, communications, and computer aspects of intelligent transportation systems. Topics include traffic flow theory fundamentals, intelligent transportation system user services, travel and traffic management, advanced vehicle safety systems, intelligent transportation system applications, architectures, standards, strategic needs assessment and deployment, and evaluation.

Focus Area 4. Artificial Intelligence and Perception:

- ME 202 - Spectral Computational Methods
- ME 233 - Artificial Intelligence for Design
- EE 142 - Pattern Recognition and Analysis of Sensor Data
- EE 146 - Computer Vision
- EE 236 - State and Parameter Estimation Theory
- EE 241 - Advanced Digital Image Processing
- EE 243 - Advanced Computer Vision
- EE 247 - Current Topics in Computer Vision and Pattern Recognition
- CS 170 - Introduction to Artificial Intelligence
- CS 171 - Introduction to Machine Learning and Data Mining
- CS 173 - Natural Language Processing
- CS 205 - Artificial Intelligence
- CS 227 - Probabilistic Models for Artificial Intelligence
- CS 235 - Data Mining Techniques

ME 202. *Spectral Computational Methods* (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): ME 200 or equivalent; ME 240A is recommended. Introduces data analysis, including discrete Fourier transforms, sampling theorem, and power spectra. Reviews Sturm-Liouville eigenfunction expansions, Gibbs phenomenon, convergence theorems, and Chebyshev transforms. Additional topics include Galerkin, tau, collocation, and pseudospectral methods, aliasing, time advancement, and numerical stability. Explores applications to incompressible Navier-Stokes equations, compressible flows, reacting flows, and complex geometries. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable as content changes.

ME 233. *Artificial Intelligence for Design* (4) Lecture, 3 hours; discussion, 1 hour.

Prerequisite(s): graduate standing or consent of instructor. Explores the application of artificial intelligence to engineering design. Topics include the use of search, knowledge-based systems, machine learning, and qualitative physical reasoning for design automation. Addresses the theory behind these techniques and issues related to their practical application. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable as content changes.

EE 142. *Pattern Recognition and Analysis of Sensor Data* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 114 or STAT 155 or consent of the instructor. Introduction to pattern recognition for multi-dimensional, multimodal sensor data such as images, videos, and smart grids. Classification and decision functions, feature extraction, regression, and neural networks. Clustering and dimensionality reduction for unsupervised learning. Dynamic models and tracking. Applications of pattern recognition in computer vision, robotics, smart grids, etc.

EE 146. *Computer Vision* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): senior standing in Computer Science or Electrical Engineering, or consent of instructor. Imaging formation, early vision processing, boundary detection, region growing, two-dimensional and three-dimensional object representation and recognition techniques. Experiments for each topic are carried out.

EE 236. *State and Parameter Estimation Theory* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215. Covers autoregressive and moving-average models; state estimation and parameter identification (including least square and maximum likelihood formulations); observability theory; synthesis of optimum inputs; Kalman-prediction (filtering and smoothing); steady-state and frequency domain analysis; online estimation; colored noise; and nonlinear filtering algorithms. Cross-listed with ME 236.

EE 241. *Advanced Digital Image Processing* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 152 or consent of instructor. Covers advanced topics in digital image processing. Examines image sampling and quantization, image transforms, stochastic image models, image filtering and restoration, and image data compression.

EE 243. *Advanced Computer Vision* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 146 or consent of instructor. EE 243 online section; enrollment in the Online Master-in Science in Engineering program. A study of three-dimensional computer vision. Topics include projective geometry, modeling and calibrating cameras, representing geometric primitives and their uncertainty, stereo vision, motion analysis and tracking, interpolating and approximating three-dimensional data, and recognition of two-dimensional and three-dimensional objects.

EE 247. *Current Topics in Computer Vision and Pattern Recognition* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 240 or EE 243 or consent of instructor. Topics include advanced methods in computer vision and pattern recognition that are evolving and of current interest. May cover novel mathematical tools; analysis of large video databases; machine learning approaches in video computing; camera networks; and biological applications of

computer vision. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 170. *Introduction to Artificial Intelligence* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 100 with a grade of “C-” or better, CS 111. An introduction to the field of artificial intelligence. Focuses on discrete valued problems. Covers heuristic search, problem representation, and classical planning. Also covers constraint satisfaction and logical inference.

CS 171. *Introduction to Machine Learning and Data Mining* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 100, MATH 010A or MATH 031. Introduces formalisms and methods in data mining and machine learning. Topics include data representation, supervised learning, and classification. Covers regression and clustering. Also covers rule learning, function approximation, and margin-based methods.

CS 173. *Natural Language Processing* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 150, may be taken concurrently. An overview of modern approaches for natural language processing. Focuses on major algorithms used in NLP for various applications such as part-of-speech tagging, parsing, named entity recognition, coreference resolution, sentiment analysis, and machine translation.

CS 205. *Artificial Intelligence* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 170 or equivalent. Examines knowledge representation and automated reasoning and their use in capturing common sense and expert knowledge. Also addresses predicate and nonmonotonic logics; resolution and term rewriting; reasoning under uncertainty; theorem provers; planning systems; and belief networks. Includes special topics in natural language processing, perception, logic programming, expert systems, and deductive databases. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 227. *Probabilistic Models for Artificial Intelligence* (4) Lecture, 3 hours; written work, 3 hours. Prerequisite(s): CS 141, STAT 155. Covers methods for representing and reasoning about probability distributions in complex domains. Focuses on graphical models and their extensions such as Bayesian networks, Markov networks, hidden Markov models, and dynamic Bayesian networks. Topics include algorithms for probabilistic inference, learning models from data, and decision making. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 235. *Data Mining Techniques* (4) Lecture, 3 hours; term paper, 1.5 hours; project, 1.5 hours per week. Prerequisite(s): CS 141, CS 166; CS 170 is recommended. CS 235 online section; enrollment in the online Master of Science in Engineering program. Provides students with a broad background in the design and use of data mining algorithms and tools. Includes clustering, classification, association rules mining, time series clustering, and Web mining. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

3. Elective Courses

Any course in the focus areas can be chosen as an elective, as long as it is not used to satisfy focus area requirements.

All other electives are listed below.

Electives from Mechanical Engineering:

- ME 114 - Introduction to Materials Science and Engineering
- ME 118 - Mechanical Engineering Modeling and Analysis
- ME 120 - Linear Systems and Controls
- ME 130 - Kinematic and Dynamic Analysis of Mechanisms
- ME 133 - Introduction to Mechatronics
- ME 153 - Finite Element Methods
- ME 176 - Sustainable Product Design
- ME 200 - Methods of Engineering Analysis
- ME 201 - Computational Methods in Engineering
- ME 203 - Design and Analysis of Engineering Experiments
- ME 210 - Sustainable Product Design
- ME 231 - Pen-Based Computing
- ME 233 - Artificial intelligence for Design
- ME 270 - Introduction to Microelectromechanical Systems
- ME 274 - Plasma-aided Manufacturing and Materials Processing

ME 114. *Introduction to Materials Science and Engineering* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 001B, PHYS 040C; upper-division standing. Covers materials classification, atomic structure and interatomic bonding, crystal structure of metals, imperfections in solids, diffusion, mechanical properties of engineering materials, strengthening mechanisms, basic concepts of fracture and fatigue, phase diagrams, ceramics, polymers, and composites.

ME 118. *Mechanical Engineering Modeling and Analysis* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 046, ME 018B with a grade of "C-" or better. Introduces data analysis and modeling used in engineering through the software package MATLAB. Numerical methods include descriptive and inferential statistics, sampling and bootstrapping, fitting linear and nonlinear models to observed data, interpolation, numerical differentiation and integration, and solution of systems of ordinary differential equations. Final project involves the development and evaluation of a model for an engineering system. Credit is awarded for only one of ENGR 118 or ME 118.

ME 120. *Linear Systems and Controls* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 001A, EE 01LA, ME 103. Introduces the modeling and analysis of dynamic systems, emphasizing the common features of mechanical, hydraulic, pneumatic, thermal, electrical, and electromechanical systems. Controls are introduced through state equations, equilibrium, linearization, stability, and time and frequency domain analysis.

ME 130. *Kinematic and Dynamic Analysis of Mechanisms* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): ME 009, ME 103. Explores the kinematic analysis of planar mechanisms including linkages, cams, and gear trains. Introduces concepts of multibody dynamics.

ME 133. *Introduction to Mechatronics* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): ME 120. Introduces hardware, software, sensors, actuators, physical systems models, and control theory in the context of control system implementation. Covers data acquisition (Labview), sensors, actuators, electric circuits and components, semiconductor electronics, logic circuits, signal processing using analog operational amplifiers, programmable logic controllers, and microcontroller programming and interfacing. Uses MATLAB and Simulink.

ME 153. *Finite Element Methods* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): ME 118. Covers weak form formulation, the Galerkin method and its computational implementation, mesh generation, data visualization, as well as programming finite element codes for practical engineering applications.

ME 176. *Sustainable Product Design* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): ME 103, ME 110, ME 113, ME 116A. Introduces the principles of sustainable product design. Topics include life cycle design; design for reliability, maintainability, and recycling/reuse/remanufacture; materials selection; and manufacturing processes. Includes project in which students analyze the environmental impact of a product and redesign it to reduce the impact. Credit is awarded for only one of ME 176 or ME 210.

ME 200. *Methods of Engineering Analysis* (4) Lecture, 4 hours. Prerequisite(s): graduate standing in engineering or consent of instructor. Topics include linear algebra theory, vector spaces, eigenvalue problems, complex analytic functions, contour integration, integral transforms, and basic methods for solving ordinary and partial differential equations in mechanical engineering applications.

ME 201. *Computational Methods in Engineering* (4) Lecture, 4 hours. Prerequisite(s): graduate standing or consent of instructor. Explores numerical methods with computer applications. Topics include solution of nonlinear algebraic equations, solution of systems of linear equations, interpolation, integration, statistical description of data, model fitting, Fast Fourier Transform and applications, and numerical solution of ordinary and partial differential equations.

ME 203. *Design and Analysis of Engineering Experiments* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. ME 203 online section; enrollment in the Online Master-in-Science in Engineering program. Introduces research methods in engineering. Topics include design of experiments, basic statistical tools, data analysis in the time-domain and frequency domain, machine learning and pattern recognition approaches, and computational tools. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

ME 210. *Sustainable Product Design* (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): graduate standing or consent of instructor. ME 210 online section; enrollment in the Online Master-in-Science in Engineering program. Introduces the principles of sustainable product design. Topics include life cycle design; design for reliability, maintainability, and recycling/reuse/remanufacture; materials selection; and manufacturing processes. Includes project in which students analyze the environmental impact of a product and redesign it to reduce the impact. May

be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Credit is awarded for only one of ME 176 or ME 210.

ME 231. *Pen-Based Computing* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor; computer programming experience. Introduces computational techniques for pen-based user interfaces. Covers fundamental issues such as ink segmentation, sketch parsing, and shape recognition. Explores the topic of sketch understanding, including reasoning about context and correcting errors. Also addresses issues related to building practical pen-based systems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with CS 233.

ME 233. *Artificial Intelligence for Design* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Explores the application of artificial intelligence to engineering design. Topics include the use of search, knowledge-based systems, machine learning, and qualitative physical reasoning for design automation. Addresses the theory behind these techniques and issues related to their practical application. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable as content changes.

ME 270. *Introduction to Microelectromechanical Systems* (4) Lecture, 4 hours. Prerequisite(s): ME 110, ME 114, or equivalents for MSE 238 online section; enrollment in the Online Master-in-Science in Engineering program. An introduction to the design and fabrication of microelectromechanical systems (MEMS). Topics include micromachining processes; material properties; transduction; applications in mechanical, thermal, optical, radiation, and biological sensors and actuators; microfluidic devices; Bio-MEMS and applications; packaging and reliability concepts; and metrology techniques for MEMS. Cross-listed with MSE 238.

ME 274. *Plasma-aided Manufacturing and Materials Processing* (4) Lecture, 4 hours. Prerequisite(s): ME 243 or equivalent; or consent of instructor. ME 274 online section; enrollment in the Online Master-in-Science in Engineering program. Covers the fundamentals of gaseous plasmas and the physics of both equilibrium and non-equilibrium discharges. Covers the basic techniques for plasma diagnostics. Discusses the use of plasmas as a materials processing medium for a variety of manufacturing processes. Advanced topics such as the processing of nanostructured materials using plasmas are included.

Electives from Electrical Engineering

Any course listed in the EE Graduate Manual in the areas Signals, Systems and Machine Intelligence (SSMI) and VLSI Circuits and Systems (VCS). Undergrad courses in the following undergrad EE focus areas are allowed: Communications, Signal Processing and Networking; Controls, Robotics and Machine Intelligence; and VLSI and Embedded Systems.

EE Graduate Manual - Signals, Systems, and Machine Intelligence:

- EE 210 - Advanced Digital Signal Processing
- EE 211 - Adaptive Signal Processing
- EE 215 - Stochastic Processes

- EE 218 - Power System Steady-state and Market Analysis
- EE 224 - Digital Communication Theory and Systems
- EE 225 - Error-Correcting Codes
- EE 226 - Wireless Communications
- EE 230 - Mathematical Methods for Electrical Engineering
- EE 231 - Convex Optimization in Engineering Application
- EE 232 - Introduction to Smart Grid
- EE 235 - Linear System Theory
- EE 236 - State and Parameter Estimation Theory
- EE 237 - Nonlinear Systems and Control
- EE 238 - Linear Multivariable Control
- EE 239 - Optimal Control
- EE 240 - Pattern recognition
- EE 241 - Advanced Digital Image Processing
- EE 243 - Advanced Computer Vision
- EE 244 - Computational Learning
- EE 245 - Advanced Robotics
- EE 246 - Intelligent Transportation Systems
- EE 249 - Power System Dynamics
- EE 250 - Information Theory
- EE 252 - Data Center Architecture
- EE 253 - Electric Power Distribution Systems
- EE 258 - Modeling and Synthesis of Cyber-Physical Systems

EE 210. *Advanced Digital Signal Processing* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 110B, EE 141. Provides in-depth coverage of advanced techniques for digital filter and power spectral estimation. Topics include digital filter design, discrete random signals, finite-word length effects, nonparametric and parametric power spectrum estimation, multi-rate digital signal processing, least square methods of digital filter design, and digital filter applications.

EE 211. *Adaptive Signal Processing* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215. Provides an in-depth understanding of adaptive signal processing techniques. Covers Wold decomposition; Yule-Walker equations; spectrum estimation; Weiner filters; linear prediction; Kalman filtering; time-varying system tracking; nonlinear adaptive filtering; and performance analysis of adaptive algorithms and their variations including stochastic gradient, least mean square, least squares, and recursive least squares.

EE 215. *Stochastic Processes* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. A study of probability and stochastic processes. Topics include discrete and continuous random variables; probability densities; characteristic functions; convergence of random sequences; central limit theorem; autocorrelation functions and spectral densities; wide-sense and strict-sense stationarity; Markov chains and processes; and response of linear time-invariant systems to random signals.

EE 218. *Power System Steady State and Market Analysis* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): EE 155; EE 132; ENGR 160 or EE 231. EE 218 online section; enrollment in the Online Master-in-Science in Engineering program. Introduces power system steady state and market analysis. Topics include system security criteria and security assessment; state estimation; automatic generation control; contingency screening and security constrained optimal power flow; the electricity market structure; security constrained economic dispatch and unit commitment; financial transmission rights; forward markets; and market power. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 224. *Digital Communication Theory and Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 115, MATH 149A, MATH 149B; or equivalents. Provides an overview of basic communication techniques and an introduction to optimum signal detection and correction. Topics include sampling and bandwidth; pulse code modulation; line coding and pulse shaping; delta modulation; stochastic approach to bandwidth and noise corruption; white Gaussian noise; matched filter; optimum signal detection; Shannon theorems; and error correction. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 225. *Error-Correcting Codes* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215 or consent of instructor. Provides an overview of basic error-correcting techniques used in data transmission and storage. Topics include groups and Galois fields, error-correction capability and code design of Hamming codes, cyclic codes, Bose-Chaudhuri-Hocquengem (BCH) codes, and Reed-Solomon codes. Also considers concatenated design and decoding techniques.

EE 226. *Wireless Communications* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215, EE 224. Presentation of fundamental cellular concepts and new techniques in wireless communications. Topics include cellular systems and standards, frequency reuse, system capacity, channel allocation, cellular radio propagation, fading channel modeling and equalization, spread spectrum communications and other multiple access techniques, and wireless networking.

EE 230. *Mathematical Methods for Electrical Engineers.* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Covers fundamental theoretical concepts and computational tools for Electrical Engineering graduate students. Presents material relevant to electrical engineering applications. Topics include vector spaces; partitioned, unitary, and positive definite matrices; differential calculus with matrices; matrix decompositions; linear system solution; convex optimization; the Lagrangian method; KKT conditions; and nonlinear optimization methods. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 230. *Mathematical Methods for Electrical Engineers* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Covers fundamental theoretical concepts and computational tools for Electrical Engineering graduate students. Presents material relevant to electrical engineering applications. Topics include vector spaces; partitioned, unitary, and positive definite matrices; differential calculus with matrices; matrix decompositions; linear

system solution; convex optimization; the Lagrangian method; KKT conditions; and nonlinear optimization methods. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 231. *Convex Optimization in Engineering Applications* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): EE 230. Covers recognizing and solving convex optimization problems that arise in engineering applications. Explores convex sets, functions, and optimization problems. Includes basics of convex analysis, least-squares, linear and quadratic programs, semidefinite programming, minimax, and other problems. Addresses optimality conditions, duality theory, theorems of alternative and applications, interior-point methods, and applications in engineering.

EE 232. *Introduction to Smart Grid* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): graduate standing. EE 232 online section; enrollment in the Online Master-in-Science in Engineering program. An introduction to smart power grid. Covers the basics of power systems; definition and applications of smart grid; demand response and demand side management; renewable power generation and integration; smart grid communications; wide area measurement; smart grid cyber security and privacy; and economics and market issues. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 235. *Linear System Theory* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 132. Provides a review of linear algebra. Topics include the mathematical description of linear systems; the solution of state-space equations; controllability and observability; canonical and minimal realization; and state feedback, pole placement, observer design, and compensator design. Cross-listed with ME 235.

EE 236. *State and Parameter Estimation Theory* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215. Covers autoregressive and moving-average models; state estimation and parameter identification (including least square and maximum likelihood formulations); observability theory; synthesis of optimum inputs; Kalman-prediction (filtering and smoothing); steady-state and frequency domain analysis; online estimation; colored noise; and nonlinear filtering algorithms. Cross-listed with ME 236.

EE 237. *Nonlinear Systems and Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 235/ME 235. Explores nonlinear systems and control. Topics include nonlinear differential equations, second order nonlinear systems, equilibrium and phase portrait, limit cycle, harmonic analysis and describing function, Lyapunov stability theory, absolute stability, Popov and circle criterion, input-output stability, small gain theorem, averaging methods, and feedback linearization. Cross-listed with ME 237.

EE 238. *Linear Multivariable Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 235/ME 235. Investigates multivariable feedback systems, stability, performance, uncertainty, and robustness. Topics include analysis and synthesis via matrix factorization; Q-parameterization and all stabilizing controllers; frequency domain methods; and H(infinity) design and structured singular value analysis. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with ME 238.

EE 239. *Optimal Control* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 215, EE 235/ME 235. Presents the theory of stochastic optimal control systems and methods for their design and analysis. Covers principles of optimization; Lagrange's equation; linear-quadratic-Gaussian control; certainty-equivalence; the minimum principle; the Hamilton-Jacobi-Bellman equation; and the algebraic Riccati equation. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with ME 239.

EE 240. *Pattern Recognition* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 141 or consent of instructor. EE 240 online section; enrollment in the Online Master-in-Science in Engineering program. Covers basics of pattern recognition techniques. Topics include hypothesis testing, parametric classifiers, parameter estimation, nonparametric density estimation, nonparametric classifiers, feature selection, discriminant analysis, and clustering.

EE 241. *Advanced Digital Image Processing* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 152 or consent of instructor. Covers advanced topics in digital image processing. Examines image sampling and quantization, image transforms, stochastic image models, image filtering and restoration, and image data compression.

EE 243. *Advanced Computer Vision* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 146 or consent of instructor. EE 243 online section; enrollment in the Online Master-in-Science in Engineering program. A study of three-dimensional computer vision. Topics include projective geometry, modeling and calibrating cameras, representing geometric primitives and their uncertainty, stereo vision, motion analysis and tracking, interpolating and approximating three-dimensional data, and recognition of two-dimensional and three-dimensional objects.

EE 244. *Computational Learning* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. Explores fundamental computational learning techniques. Topics include elements of learning systems, inductive learning, analytic learning, case-based learning, genetic learning, connectionist learning, reinforcement learning and integrated learning techniques, and comparison of learning paradigms and applications.

EE 245. *Advanced Robotics* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 236/ME 236; ME 120 or equivalent. Topics include robot navigation; description of robot sensors and their characteristics; sensor data processing; feature extraction; and matching. Also covers representations of space for mapping; map based localization; simultaneous localization and mapping; image-based motion estimation; and motion planning. Cross-listed with ME 222.

EE 246. *Intelligent Transportation Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. EE 115 and EE 132 are recommended. Focuses on the control, communications, and computer aspects of intelligent transportation systems. Topics include traffic flow theory fundamentals, intelligent transportation system user services, travel and traffic management, advanced vehicle safety systems, intelligent transportation system applications, architectures, standards, strategic needs assessment and deployment, and evaluation.

EE 249. *Power System Dynamics* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): EE 218 or EE 232; EE 153 or EE 155. Introduces dynamic phenomena in power systems following disturbances. Topics include synchronous machines, voltage stability, power system reliability criteria, synchronous machine modeling, power system stability criterion under classical models, and time domain simulation. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 250. *Information Theory* (4) Lecture, 3 hours; extra reading, 3 hours. Prerequisite(s): EE 215. An overview of fundamental limitations imposed on communication systems. Topics include Shannon's information measures, weak and strong typicality, lossless data compression, source and channel models and Shannon's coding theorems, channel capacity and the rate-distortion function, Gaussian sources and channels, and limits of communication between multiple terminals.

EE 252. *Data Center Architecture* (4) Lecture, 3 hours; extra reading, 2 hours; term paper, 1 hour. Prerequisite(s): CS 161 or consent of instructor. Introduces recent trends and challenges of warehouse-scale computing and data center systems. Topics include virtualization, resource management, data market, power management, sustainable computing, and demand response.

EE 253. *Electric Power Distribution Systems* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): EE 155, graduate standing; or consent of instructor. Covers fundamentals of the operation and planning of electric power distribution systems. Topics include electric load modeling, overhead and underground lines, three-phase transformers, voltage regulation, three-phase unbalanced power flow, three-phase optimal power flow, and system protection. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 258. *Modeling and Synthesis of Cyber Physical Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Introduces trends and challenges of modern cyber-physical systems. Reviews state-of-the-art design approaches and tools in both academia and industry. Introduces fundamental concepts in functional modeling, real-time embedded architecture, design synthesis and validation. Introduces emerging design principles and their applications in automotive, avionics, smart buildings, and consumer electronics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Cross-listed with CS 256.

VLSI Circuits and Systems (formerly Computer Engineering):

- EE 201 - Applied Quantum Mechanics
- EE 202 - Fundamentals of Semiconductors and Nanostructures
- EE 203 - Solid State Devices
- EE 213 - Computer-Aided Electronic Circuit Simulation
- EE 215 - Stochastic Processes
- EE 217 - GPU Architecture and Parallel Programming
- EE 219 - Advanced CMOS technology
- EE 221 - Radio-Frequency Integrated Circuit Design

- EE 222 - Advanced Radio-Frequency Integrated Circuit Design
- EE 230 - Mathematical Methods for Electrical Engineering
- EE 235 - Linear System Theory
- EE 240 - Pattern Recognition
- EE 243 - Advanced Computer Vision
- EE 252 - Data Center Architecture
- EE 255 - Real-Time Embedded Systems
- CS 201 - Compiler Construction
- CS 202 - Advanced Operating Systems
- CS 203 - Advanced Computer Architecture
- CS 218 - Design and Analysis of Algorithms

EE 201. *Applied Quantum Mechanics* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 046, PHYS 040A; or consent of instructor. Covers topics in quantum mechanics including Schrodinger equation; operator formalism; harmonic oscillator; quantum wells; spin, bosons, and fermions; solids; perturbation theory; Wentzel-Kramers Brillouin approximation; tunneling; tight-binding model; quantum measurements; quantum cryptography; and quantum computing. Cross-listed with MSE 207.

EE 202. *Fundamentals of Semiconductors and Nanostructures* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 133, EE 201/MSE 207; or consent of instructor. Examines principles of semiconductor materials and nanostructures. Topics include periodic structures, electron and phonon transport, defects, optical properties, and radiative recombination. Also covers absorption and emission of radiation in nanostructures and nonlinear optics effects. Emphasizes properties of semiconductor superlattices, quantum wells, wires, and dots. Cross-listed with MSE 217.

EE 203. *Solid-State Devices* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 133 or consent of instructor. Covers electronic devices including p-n junctions, field-effect transistors, heterojunction bipolar transistors, and nanostructure devices. Explores electrical and optical properties of semiconductor heterostructures, superlattices, quantum wires, and dots, as well as devices based on these structures. Cross-listed with MSE 237C.

EE 213. *Computer-Aided Electronic Circuit Simulation* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 001A, EE 001B, EE 133. Introduction to numerical algorithms and computer-aided techniques for the simulation of electronic circuits. Covers theoretical and practical aspects of important analyses. Topics include circuit formulation methods; large-signal nonlinear direct current, small-signal alternating current, and moment matching transient; sensitivity; and noise. Also discusses recent advances in timing analysis, symbolic analysis, and radio frequency circuit analysis.

EE 215. *Stochastic Processes* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. A study of probability and stochastic processes. Topics include discrete and continuous random variables; probability densities; characteristic functions;

convergence of random sequences; central limit theorem; autocorrelation functions and spectral densities; wide-sense and strict-sense stationarity; Markov chains and processes; and response of linear time-invariant systems to random signals.

EE 217. *GPU Architecture and Parallel Programming* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 160 with a grade of “C-” or better or consent of instructor. Introduces the popular CUDA based parallel programming environments based on Nvidia GPUs. Covers the basic CUDA memory/threading models. Also covers the common data-parallel programming patterns needed to develop a high-performance parallel computing applications. Examines computational thinking; a broader range of parallel execution models; and parallel programming principles. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. May be taken Satisfactory (S) or No Credit (NC) by students advanced to candidacy for the Ph.D. Cross-listed with CS 217.

EE 219. *Advanced Complementary Metal Oxide Semiconductor (CMOS) Technology* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 203/MSE 237C. Introduces advanced complementary metal oxide semiconductor (CMOS) technology. Topics include MOS field effect transistor (MOSFET) scaling; short and narrow channel effects; high field effects; vertical MOSFET transistors; single electron transistors; MOSFET nonvolatile memory devices; and small- and large-signal MOSFET models. Covers CMOS process integration. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 221. *Radio-Frequency Integrated Circuit Design* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 100B; senior or graduate standing. Covers the essentials of contemporary radio frequency (RF) complimentary metal oxide semiconductor (CMOS) integrated circuit (IC) analysis and design. Addresses typical RF building blocks in CMOS and bipolar/CMOS (BiCMOS) technologies, including passive IC components, transistors, distributed networks, voltage reference and biasing circuits, power amplifiers, and feedback networks. Also covers RF device modeling, bandwidth estimation, and stability analysis techniques.

EE 222. *Advanced Radio-Frequency (RF) Integrated Circuit Design* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 100B; senior or graduate standing. Covers analysis techniques for nonlinear effects and noise in RF integrated circuit design. Addresses nonlinear, and distortion behavior, including intermodulation, cross-modulation, harmonics, gain compression, and desensitization. Also explores noise effects, including thermal, short, flicker, and burst noises. Includes single-stage and multiple-stage networks.

EE 230. *Mathematical Methods for Electrical Engineers* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Covers fundamental theoretical concepts and computational tools for Electrical Engineering graduate students. Presents material relevant to electrical engineering applications. Topics include vector spaces; partitioned, unitary, and positive definite matrices; differential calculus with matrices; matrix decompositions; linear system solution; convex optimization; the Lagrangian method; KKT conditions; and nonlinear optimization methods. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

EE 235. *Linear System Theory* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 132. Provides a review of linear algebra. Topics include the mathematical description of linear systems; the solution of state-space equations; controllability and observability; canonical and minimal realization; and state feedback, pole placement, observer design, and compensator design. Cross-listed with ME 235.

EE 240. *Pattern Recognition* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 141 or consent of instructor. EE 240 online section; enrollment in the Online Master-in-Science in Engineering program. Covers basics of pattern recognition techniques. Topics include hypothesis testing, parametric classifiers, parameter estimation, nonparametric density estimation, nonparametric classifiers, feature selection, discriminant analysis, and clustering.

EE 243. *Advanced Computer Vision* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): EE 146 or consent of instructor. EE 243 online section; enrollment in the Online Master-in-Science in Engineering program. A study of three-dimensional computer vision. Topics include projective geometry, modeling and calibrating cameras, representing geometric primitives and their uncertainty, stereo vision, motion analysis and tracking, interpolating and approximating three-dimensional data, and recognition of two-dimensional and three-dimensional objects.

EE 252. *Data Center Architecture* (4) Lecture, 3 hours; extra reading, 2 hours; term paper, 1 hour. Prerequisite(s): CS 161 or consent of instructor. Introduces recent trends and challenges of warehouse-scale computing and data center systems. Topics include virtualization, resource management, data market, power management, sustainable computing, and demand response.

EE 255. *Real-Time Embedded Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 120B/CS 120B, or equivalent; consent of instructor. Covers the fundamentals and principles of real-time embedded systems. Topics include uniprocessor and multiprocessor real-time scheduling, real-time operating systems, synchronization, resource reservation, memory management, power management, etc. Introduces mathematical techniques for real-time system analysis. Offers hands-on experience with designing, implementing, and evaluating real-time systems on embedded platforms. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 201. *Compiler Construction* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 152. Covers theory of parsing and translation. Also addresses compiler construction including lexical analysis, syntax analysis, code generation, and optimization. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 202. *Advanced Operating Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 153. Examines recent developments in operating systems. Also covers multiprogramming, parallel programming, time sharing, scheduling and resource allocation, and selected topics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 203. *Advanced Computer Architecture* (4) Lecture, 3 hours; research, 3 hours.

Prerequisite(s): CS 161. Covers contemporary computer systems architecture including pipelined CPU design, instruction level parallelism (ILP), memory hierarchy, thread level parallelism, introduction to multiprocessing, and evaluation of computer performance. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 218. *Design and Analysis of Algorithms* (4) Lecture, 3 hours; outside research, 3 hours.

Prerequisite(s): CS 141. A study of efficient data structures and algorithms for solving problems from a variety of areas such as sorting, searching, selection, linear algebra, graph theory, and computational geometry. Also covers worst-case and average-case analysis using recurrence relations, generating functions, upper and lower bounds, and other methods. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

Undergrad EE Focus area - Communications, Signal Processing, and Networking:

- EE 115 - Introduction to Communication Systems
- EE 117 - Electromagnetics II
- EE 118 - Radio Frequency Circuit Design
- EE 128 - Data Acquisition, Instrumentation, and Process Control
- EE 141 - Digital Signal Processing
- EE 146 - Computer Vision
- EE 150 - Digital Communication
- EE 152 - Digital Image Processing
- ENGR 160 - Introduction to Engineering Optimization Techniques

EE 115. *Introduction to Communication Systems* (4) Lecture, 3 hours; laboratory, 3 hours.

Prerequisite(s): EE 110B. Covers spectral density and correlation, modulation theory, amplitude, frequency, phase and analog pulse modulation and demodulation techniques, signal-to-noise ratios, and system performance calculations. Laboratory experiments involve techniques of modulation and demodulation.

EE 117. *Electromagnetics II* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 116.

Covers applications of Maxwell's equations. Includes skin effect, boundary value problems, plane waves in lossy media, transverse EM waves, hollow metal waveguides, cavity resonators, microstrips, propagation in dielectrics and optical fibers, optical fibers applications, radiation, and antennas. Covers theoretical and computer modeling exercises in basic electromagnetic technology.

EE 118. *Radio Frequency Circuit Design* (4) Lecture, 3 hours; laboratory, 3 hours.

Prerequisite(s): EE 116, EE 100B (EE 116 and | 289 EE 100B may be taken concurrently).

Studies design and analysis of radio frequency (RF) circuits. Topics include multiport networks, scattering matrix and S-parameters; transmission lines, matching networks; Smith Chart; RF electromagnetic analysis of waveguides, antennas, filters and couplers; RF transistor equivalent modeling, low-noise amplifier design, noise figure, oscillators and mixers, and phase lock loop.

EE 128. *Data Acquisition, Instrumentation, and Process Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 100B, EE 120B/CS 120B (EE 100B and EE 120B/CS 120B may be taken concurrently); or consent of instructor. Covers analog signal transducers, conditioning, and processing; step motors, DC servo motors, and other actuation devices. Explores analog to digital and digital to analog converters; data acquisition systems; microcomputer interfaces to commonly used sensors and actuators; and design principles for electronic instruments, real time process control, and instrumentation.

EE 141. *Digital Signal Processing* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 110B. Transform analysis of Linear Time-Invariant (LTI) systems, discrete Fourier Transform (DFT) and its computation, Fourier analysis of signals using the DFT, filter design techniques, structures for discrete-time systems. Laboratory experiments on DFT, fast Fourier transforms (FFT), infinite impulse response (IIR), and finite impulse response (FIR) filter design, and quantization effects.

EE 146. *Computer Vision* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): senior standing in Computer Science or Electrical Engineering, or consent of instructor. Imaging formation, early vision processing, boundary detection, region growing, two-dimensional and three-dimensional object representation and recognition techniques. Experiments for each topic are carried out.

EE 150. *Digital Communications* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 114, EE 115. Topics include modulation, probability and random variables, correlation and power spectra, information theory, errors of transmission, equalization and coding methods, shift and phase keying, and a comparison of digital communication systems.

EE 152. *Digital Image Processing* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 110B or EE 111 or consent of instructor. Digital image acquisition, image enhancement and restoration, image compression, computer implementation and testing of image processing techniques. Students gain hands-on experience of complete image processing systems, including image acquisition, processing, and display through laboratory experiments.

ENGR 160. *Introduction to Engineering Optimization Techniques* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A; CS 010 or EE 020 or ME 018A and ME 018B. ENGR 160 online section; enrollment in the Master-in-Science in Engineering program. Introduction to formulating and solving optimization problems in engineering. Includes single-variable and multi-variable optimization; linear programming - simplex method; nonlinear unconstrained optimization - gradient, steepest descent, and Newton methods; and nonlinear constrained optimization - gradient projection methods. Addresses applications of optimization in engineering design problems. Solves various engineering optimization examples using MATLAB.

Undergrad EE Focus area - Controls, Robotics and Machine Intelligence:

- EE 128 - Data Acquisition, Instrumentation, and Process Control
- EE 132 - Automatic Control
- EE 142 - Pattern Recognition and Analysis of Sensor Data

- EE 144 - Introduction to Robotics
- EE 145/ME 145 - Robotic Planning and Kinematics
- EE 146 - Computer Vision
- EE 151 - Introduction to Digital Control
- EE 152 - Digital Image Processing
- ENGR 160 - Introduction to Engineering Optimization Techniques

EE 128. *Data Acquisition, Instrumentation, and Process Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 100B, EE 120B/CS 120B (EE 100B and EE 120B/CS 120B may be taken concurrently); or consent of instructor. Covers analog signal transducers, conditioning, and processing; step motors, DC servo motors, and other actuation devices. Explores analog to digital and digital to analog converters; data acquisition systems; microcomputer interfaces to commonly used sensors and actuators; and design principles for electronic instruments, real time process control, and instrumentation.

EE 132. *Automatic Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 105 or ME 103 or equivalent; EE 110A or ENGR 118; or consent of instructor. Covers mathematical modeling of linear systems for time and frequency domain analysis. Topics include transfer function and state variable representations for analyzing stability, controllability, and observability; and closed-loop control design techniques by Bode, Nyquist, and root-locus methods. Laboratories involve both simulation and hardware exercises.

EE 142. *Pattern Recognition and Analysis of Sensor Data* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): EE 114 or STAT 155 or consent of the instructor. Introduction to pattern recognition for multi-dimensional, multimodal sensor data such as images, videos, and smart grids. Classification and decision functions, feature extraction, regression, and neural networks. Clustering and dimensionality reduction for unsupervised learning. Dynamic models and tracking. Applications of pattern recognition in computer vision, robotics, smart grids, etc.

EE 144. *Introduction to Robotics* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 132. Covers basic robot components from encoders to microprocessors. Kinematic and dynamic analysis of manipulators. Addresses open- and closed-loop control strategies, task planning, contact and noncontact sensors, robotic image understanding, and robotic programming languages. Experiments and projects include robot arm programming, robot vision, and mobile robots. Cross-listed with ME 144.

EE 145/ME 145. *Robotic Planning and Kinematics* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): ME 120 or equivalent; or consent on instructor. Motion planning and kinematics topics with an emphasis in geometric reasoning, programming, and matrix computations. Motion planning includes configuration spaces, sensor based planning, decomposition and sampling methods, and advanced planning algorithms. Kinematics includes reference frames, rotations and displacements, and kinematic motion models. Cross-listed with ME 145.

EE 146. *Computer Vision* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): senior standing in Computer Science or Electrical Engineering, or consent of instructor. Imaging formation, early vision processing, boundary detection, region growing, two-dimensional and

three-dimensional object representation and recognition techniques. Experiments for each topic are carried out.

EE 151. *Introduction to Digital Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 132, EE 141. Review of continuous-time control systems; review of Z-transform and properties; sampled-data systems; stability analysis and criteria; frequency domain analysis and design; transient and steady-state response; state-space techniques; controllability and observability; pole placement; observer design; Lyapunov stability analysis. Laboratory experiments complementary to these topics include simulations and hardware design.

EE 152. *Digital Image Processing* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 110B or EE 111 or consent of instructor. Digital image acquisition, image enhancement and restoration, image compression, computer implementation and testing of image processing techniques. Students gain hands-on experience of complete image processing systems, including image acquisition, processing, and display through laboratory experiments.

ENGR 160. *Introduction to Engineering Optimization Techniques* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A; CS 010 or EE 020 or ME 018A and ME 018B. ENGR 160 online section; enrollment in the Master-in-Science in Engineering program. Introduction to formulating and solving optimization problems in engineering. Includes single-variable and multi-variable optimization; linear programming - simplex method; nonlinear unconstrained optimization - gradient, steepest descent, and Newton methods; and nonlinear constrained optimization - gradient projection methods. Addresses applications of optimization in engineering design problems. Solves various engineering optimization examples using MATLAB.

Undergrad EE Focus area - VLSI and Embedded Systems:

- EE 128 - Data Acquisition, Instrumentation, and Process Control
- EE 135 - Analog Integrated Circuit Layout and Design
- EE 147 - Graphics Processing Unit Computing and Programming
- EE 165 - Design for Reliability of Integrated Circuits and Systems
- EE 168/CS 168 - Introduction to Very Large Scale Integration (VLSI) and Design
- CS 161 - Design and Architecture of Computer Systems
- ENGR 160 - Introduction to Engineering Optimization Techniques

EE 128. *Data Acquisition, Instrumentation, and Process Control* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 100B, EE 120B/CS 120B (EE 100B and EE 120B/CS 120B may be taken concurrently); or consent of instructor. Covers analog signal transducers, conditioning, and processing; step motors, DC servo motors, and other actuation devices. Explores analog to digital and digital to analog converters; data acquisition systems; microcomputer interfaces to commonly used sensors and actuators; and design principles for electronic instruments, real time process control, and instrumentation.

EE 135. *Analog Integrated Circuit Layout and Design* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 100B or consent of instructor. Covers analog circuit design, layout, and

verification of complementary metal oxide semiconductors (CMOSs) with use of computer-aided design tools. Topics covered include analog metal oxide semiconductor field effect transistor (MOSFET) models, current sources, references, amplified design, nonlinear analog circuits, dynamic analog circuits, analog-to-digital converters (ADCs), and digital-to-analog converters (DACs).

EE 147. *Graphics Processing Unit Computing and Programming* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 120B/ EE 120B or equivalent; consent of instructor. Introduces principles and practices of programming graphics processing units (GPUs) using the parallel programming environment. Covers memory/threading models, common data-parallel programming patterns and libraries needed to develop high-performance parallel computing applications. Examines computational thinking; a broader range of parallel execution models; and parallel programming principles.

EE 165. *Design for Reliability of Integrated Circuits and Systems* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): EE 100A; senior or graduate standing or consent of instructor. Covers essentials of electrical transient induced failures to integrated circuits (IC) and systems. Addresses basics for different failure and testing models including electrostatic discharge (ESD). Discusses design-for-reliability (DFR) techniques such as ESD protection designs at IC, module, and system levels. Enhances learning with computer aided design (CAD) laboratories.

EE 168/CS 168. *Introduction to Very Large Scale Integration (VLSI) Design* (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): CS 120A/EE 120A or consent of instructor. Studies integrated circuit fabrication, device characterization, and circuit simulation. Introduces basic device physics and physical design rules, MOS logic design, and timing and clock schemes. Covers layout generation, subsystem designs, and circuits for alternative logic styles. Also covers design and simulation using hardware description language and CAD tools. Cross-listed with CS 168.

CS 161. *Design and Architecture of Computer Systems* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 120A/EE 120A. A study of the fundamentals of computer design. Topics include the performance evaluation of microprocessors; instruction set design and measurements of use; microprocessor implementation techniques including multicycle and pipelined implementations; computer arithmetic; memory hierarchy; and input/output (I/O) systems.

ENGR 160. *Introduction to Engineering Optimization Techniques* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A; CS 010 or EE 020 or ME 018A and ME 018B. ENGR 160 online section; enrollment in the Master-in-Science in Engineering program. Introduction to formulating and solving optimization problems in engineering. Includes single-variable and multi-variable optimization; linear programming - simplex method; nonlinear unconstrained optimization - gradient, steepest descent, and Newton methods; and nonlinear constrained optimization - gradient projection methods. Addresses applications of optimization in engineering design problems. Solves various engineering optimization examples using MATLAB.

4. Any graduate CS course listed in the Catalog under the CS Graduate Program in the Major Specialty Areas of C (Databases, Information Retrieval, Data Mining, and Machine Learning), D (Operating Systems, Distributed Systems, and High Performance Computing), or E (Computer Networks). Undergraduate CS courses CS170, CS 171, CS 172, CS 173 are also allowed.

Electives from Computer Science Databases, Information Retrieval, Data Mining, and Machine Learning:

- CS 205 - Artificial Intelligence
- CS 226 - Big-Data Management
- CS 227 - Probabilistic Models for Artificial intelligence
- CS 229 - Machine Learning
- CS 235 - Data Mining Techniques
- CS 236 - Database Management Systems
- CS 242 - Information Retrieval and Web Search

CS 205. *Artificial Intelligence* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 170 or equivalent. Examines knowledge representation and automated reasoning and their use in capturing common sense and expert knowledge. Also addresses predicate and nonmonotonic logics; resolution and term rewriting; reasoning under uncertainty; theorem provers; planning systems; and belief networks. Includes special topics in natural language processing, perception, logic programming, expert systems, and deductive databases. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 226. *Big-Data Management* (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): CS 166. Introduction to the architecture and design of big data management systems. Covers the design of distributed file systems and high throughput databases. Description of popular programming paradigms for big data including MapReduce and Resilient Distributed Datasets. Includes a course project with hands-one experience on open-source big data systems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 227. *Probabilistic Models for Artificial Intelligence* (4) Lecture, 3 hours; written work, 3 hours. Prerequisite(s): CS 141, STAT 155. Covers methods for representing and reasoning about probability distributions in complex domains. Focuses on graphical models and their extensions such as Bayesian networks, Markov networks, hidden Markov models, and dynamic Bayesian networks. Topics include algorithms for probabilistic inference, learning models from data, and decision making. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 229. *Machine Learning* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 100, STAT 155. CS 229 online section; enrollment in the Online Master-in-Science in Engineering program. A study of supervised machine learning that emphasizes discriminative methods. Covers the areas of regression and classification. Topics include linear methods, instance-based learning, neural networks, kernel machines, and additive models. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 235. *Data Mining Techniques* (4) Lecture, 3 hours; term paper, 1.5 hours; project, 1.5 hours per week. Prerequisite(s): CS 141, CS 166; CS 170 is recommended. CS 235 online section; enrollment in the online Master of Science in Engineering program. Provides students with a broad background in the design and use of data mining algorithms and tools. Includes clustering, classification, association rules mining, time series clustering, and Web mining. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 236. *Database Management Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 141; CS 153 or equivalent; CS 166; or consent of instructor. Covers principles of file systems; architecture of database management systems; data models; and relational databases. Also examines logical and physical design of databases; hardware and software implementation of database systems; and distributed databases (e.g., query processing, concurrences, recovery). May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 242. *Information Retrieval and Web Search* (4) Lecture, 3 hours; term paper, 1.5 hours; project, 1.5 hours per week. Prerequisite(s): CS 141, CS 166. CS 242 online section; enrollment in the online Master of Science in Engineering program. Introduces Information Retrieval (IR) principles and techniques for indexing and searching document collections with special emphasis on Web search. Includes text processing, ranking algorithms, search in social networks, search evaluation, and search engines scalability. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

Operating Systems, Distributed Systems, and High Performance Computing:

- CS 202 - Advanced Operating Systems
- CS 211 - High Performance Computing
- CS 237 - Advanced Topics in Modeling and Simulation
- CS 253 - Distributed Systems
- CS 255 - Computer Security

CS 202. *Advanced Operating Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 153. Examines recent developments in operating systems. Also covers multiprogramming, parallel programming, time sharing, scheduling and resource allocation, and selected topics. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 211. *High Performance Computing* (4) Lecture, 3 hours; research, 3 hours. Prerequisite(s): CS 161 or consent of instructor. Introduces performance optimization for sequential computer programs. Covers high performance computing on multicore shared memory computers and on distributed memory computing clusters. Also covers high performance scientific libraries and computing application development using threads, | 230 OpenMP, and Message Passing Interface (MPI) parallel file systems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 237. *Advanced Topics in Modeling and Simulation* (4) Lecture, 3 hours; research, 3 hours. Prerequisite(s): CS 177. Covers formal computer simulation models such as Discrete Event Specified Models and differential equation models. Examines current developments in simulation languages. Also addresses integrated model development and its applications to complex, large-scale problems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 253. *Distributed Systems* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 153. Integrates the theory and practice of distributed systems with a focus on recent developments in distributed systems. Includes middleware architectures; distributed process management and real-time scheduling; dependability; and group communication protocols. Also covers distributed process management; replication; large-scale peer-to-peer systems; Internet content delivery; and Web caching. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 255. *Computer Security* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 153 or CS 164 or CS 165. Discusses the theoretical and practical issues arising in the context of computer systems security and the principles underlying the design of secure computing environments. Topics include cryptography, security models, authentication protocols, network security, intrusion detection, attacks and their countermeasures, and secure systems design. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

Computer Networks:

- CS 204 - Advanced Computer Networks
- CS 208 - Cloud Computing and Cloud Networking
- CS 237 - Advanced Topics in Modeling and Simulation
- CS 239 - Performance Evaluation of Computer Networks
- CS 240 - Network routing
- CS 254 - Network Security
- CS 255 - Computer Security
- CS 257 - Wireless Networks and Mobile Computing

CS 204. *Advanced Computer Networks* (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): CS 014 with a grade of "C-" or better, CS 164. Covers advanced topics in computer networks, layering, Integrated Services Digital Networks (ISDN), and high-speed networks. Also covers performance models and analysis, distributed systems and databases, and case studies. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 208. *Cloud Computing and Cloud Networking* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 164, CS 153, or equivalent. Covers cloud computing concepts. Introduces operating system virtualization techniques enabling multi-tenant cloud computing. Study of operating system scheduling concepts, virtualization, cloud resource management, VM migration and security. Overview of data center networking, networking cloud data centers, virtual private

clouds, replication, disaster recovery and green computing. Examination of commercial cloud platforms.

CS 237. *Advanced Topics in Modeling and Simulation* (4) Lecture, 3 hours; research, 3 hours. Prerequisite(s): CS 177. Covers formal computer simulation models such as Discrete Event Specified Models and differential equation models. Examines current developments in simulation languages. Also addresses integrated model development and its applications to complex, large-scale problems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 239. *Performance Evaluation of Computer Networks* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 164. Offers models and analytical techniques for evaluating the performance of computer networks. Covers basic and intermediate queuing theory and queuing networks and their application to practical systems. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 240. *Network Routing* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 141 or CS 204; CS 164. An in-depth study of routing in computer networks. Examines general principles and specific routing protocols and technologies. Topics include Internet, Asynchronous Transfer Mode (ATM), optical, wireless, and ad hoc networks. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 254. *Network Security* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 165. Introduces the security problems in the networking domain, attacks and defenses, vulnerabilities in various network protocols. Topics include protocol security of DNS, TCP/ IP, SSL/TLS, applied cryptography, network side channel attacks, firewalls, censorship technology, internet measurement. Guides students to conduct small-scale research projects. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor. Course is repeatable.

CS 255. *Computer Security* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 153 or CS 164 or CS 165. Discusses the theoretical and practical issues arising in the context of computer systems security and the principles underlying the design of secure computing environments. Topics include cryptography, security models, authentication protocols, network security, intrusion detection, attacks and their countermeasures, and secure systems design. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

CS 257. *Wireless Networks and Mobile Computing* (4) Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): CS 141; CS 164 or CS 204. Introduces basic and advanced concepts of wireless networks and mobile computing. Covers both wireless cellular and ad hoc networks. Includes protocols for medium access control, resource allocation, and routing, as well as transport layer optimizations for the wireless environment. Also covers standards, Bluetooth, and the IEEE 802.11 for wireless local area networks. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

Undergraduate CS courses:

- CS 170 - Introduction to Artificial Intelligence
- CS 171 - Introduction to Machine Learning and Data Mining
- CS 172 - Introduction to Information Retrieval
- CS 173 - Natural Language Processing

CS 170. *Introduction to Artificial Intelligence* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 100 with a grade of “C-” or better, CS 111. An introduction to the field of artificial intelligence. Focuses on discrete valued problems. Covers heuristic search, problem representation, and classical planning. Also covers constraint satisfaction and logical inference.

CS 171. *Introduction to Machine Learning and Data Mining* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 100, MATH 010A or MATH 031. Introduces formalisms and methods in data mining and machine learning. Topics include data representation, supervised learning, and classification. Covers regression and clustering. Also covers rule learning, function approximation, and margin-based methods.

CS 172. *Introduction to Information Retrieval* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 100; CS 111; EE 114 or STAT 155. Introduces information retrieval (IR) principles and techniques for indexing and searching document collections. Topics include Web search, text processing, ranking algorithms, search in social networks, and search evaluation. Also studies scalability issues in search engines. Satisfactory (S) or No Credit (NC) grading is not available.

CS 173. *Natural Language Processing* (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 150, may be taken concurrently. An overview of modern approaches for natural language processing. Focuses on major algorithms used in NLP for various applications such as part-of-speech tagging, parsing, named entity recognition, coreference resolution, sentiment analysis, and machine translation.

SECTION VI: RESOURCE REQUIREMENTS

All the technical resources required by the M.S. Robotics program are already available in and for the three participating departments including computing facilities, library resources, teaching laboratories and research facilities.

The only additional resources would be office space and one FTE for administrative support (initial support may be less than 1 FTE, ramping up as the program goes).

SECTION VII: GRADUATE STUDENT SUPPORT

MS Robotics students are expected to be self-supported. However, GSR and Teaching Assistantships may be available on a case-by-case basis.

SECTION VIII: GOVERNANCE

The program will be led by a Program Director, assisted by an Associate Director. While the Director will focus on the overall program and coordination among the departments, the Associate Director will serve the role of Graduate Advisor taking care of all graduate student advising issues within the program. A staff will help the faculty Directors in administering the program. The Program Director will rotate among the 3 departments. The Associate Director will be from a different department than the Director and this position will also rotate between the departments. The staff will report to the Director and the Director will report to the Dean of BCoE.

A core group of faculty will be appointed to oversee the program and coordinate efforts with the departments. This Oversight Committee will be led by the Director and Associate Director and comprise of faculty from all three departments. The committee will have an equitable distribution of faculty from the three departments and the different technical areas of interest to the program.



Academic Senate

GRADUATE COUNCIL

October 15, 2020

To: Jason Stajich, Chair
Riverside Division

From: Amanda Lucia, Chair
Graduate Council

A handwritten signature in blue ink that reads "Amanda Lucia".

Re: New Master's Degree Proposal: 2nd Round-Master of Science Degree in
Robotics

The Graduate Council reviewed the second version of the Master of Science Degree in Robotics at their October 15, 2020 meeting. The Council agreed that the appropriate revisions were made and voted to approve the proposal as written.



COMMITTEE ON DIVERSITY, EQUITY, & INCLUSION

October 20, 2020

To: Jason Stajich
Riverside Division Academic Senate

From: Xuan Liu, Chair
Committee on Diversity, Equity, & Inclusion


Re: [Campus Review] New Master Degree Proposal: *2nd Round-Master of Science Degree in Robotics*

The Committee on Diversity, Equity and Inclusion (CODEI) discussed the New Master Degree Proposal: Master of Science Degree in Robotics at its October 15th meeting and unanimously supports the proposal. The Committee commends the program for its commitment to Diversity, Equity, and Inclusion, not only in terms of student recruitment and retention, but also in terms of its willingness to address these issues in the curriculum; algorithmic bias in artificial intelligence causes harm worldwide to many members of non-dominant groups, and it is of paramount importance that all members of society actively work to remedy the resulting inequities.



October 20, 2020

To: Jason Stajich, Chair
Riverside Division

From: Katherine Kinney, Chair 
Committee on Planning and Budget

RE: New Master's Degree Proposal: 2nd Round-Master of Science Degree in Robotics

The Committee on Planning and Budget discussed the revised proposal for a new Master of Science Degree in Robotics at their October 20, 2020 meeting. The committee was supportive of the revised proposal.



Academic Senate

October 23, 2020

To: Jason Stajich, Chair
Riverside Division

From: Alejandra Dubcovsky, Chair
Committee on Library and Information Technology

Re: 20-21. CR. Master of Science Degree in Robotics

The Committee on Library and Information Technology reviewed the Master of Science Degree in Robotics at their October 15, 2020 meeting and did not note any concern relating to the Committee's charge of Library and Information Technology.