Rochester Institute of Technology

Department of Electrical and Microelectronic Engineering

Kate Gleason College of Engineering

EME Graduate Program Guide 2016-2017

Welcome

Welcome to the Electrical and Microelectronic Engineering Department at the Rochester Institute of Technology. Our exciting profession is at the forefront of many transformational innovations including cell phones, media players, lasers, medical diagnosis systems, and multimedia workstations to name but a few. We provide strong, rigorous curricula that prepares students to enter the professional workforce and/or pursue further graduate studies in their field of interest. Our graduates are highly sought after by leading employers and top graduate and professional schools in the country. Surveys consistently confirm that an advanced degree in engineering provide significantly more career opportunities than a standard four year program. The Electrical and Microelectronic Engineering Department offers a number of full and part time graduate programs and is supported by a wide range of highly experienced, internationally renowned faculty and staff; and world class laboratories and facilities. We offer numerous graduate courses in multiple disciplines and concentrations. Furthermore, our faculty conduct state of the art sponsored research for government agencies and industrial partners. Our work is routinely cited in leading journals and periodicals.

The objective of this document is to provide guidance for students pursuing a Master's degree in the Department of Electrical and Microelectronic Engineering. There are three separate degrees within the department for which this guide applies. They are the following

- Master of Science in Electrical Engineering (EEEE-MS)
- Master of Science in Microelectronic Engineering (MCEE-MS)
- Master of Engineering in Microelectronic Manufacturing Engineering (MCEMANU-ME)

This document is intended to provide pertinent information concerning each of these degrees. It also contains multiple sections devoted to common issues such as thesis formats and binding etc. These guidelines outline the expectations of the Department of Electrical and Microelectronic Engineering and the Rochester Institute of Technology as well as the responsibilities of the student, thesis supervisor, and committee members**.**

Table of Contents

1. Contact Information

Department of Electrical and Microelectronic Engineering
Rochester Institute of Technology
79 Lomb Memorial Drive
Rochester, NY 14623
Phone (585) 475-2164
http://www.rit.edu/kgcoe/electrical/
http://www.rit.edu/kgcoe/microelectronic

Dr. Sohail Dianat, Professor and Department Head
Electrical and Microelectronic Engineering
79 Lomb Memorial Drive
Rochester, NY 14623
Phone (585) 475-2164
Email: sadeee@rit.edu

Ms. Patricia Vicari, Graduate Sr. Staff Specialist
79 Lomb Memorial Drive
Rochester, NY 14623
Phone (585) 475-2164
Email: pmveee@rit.edu

Dr. Jayanti Venkataraman, Graduate Program Director EME Gleason
Professor Department of Electrical and Microelectronic Engineering
Rochester Institute of Technology
Bldg 09, Office 3091
79 Lomb Memorial Drive
Rochester, NY 14623
Phone (585) 475-2143
Email: jnveee@rit.edu
http://www.rit.edu/kgcoe/eta/

Dr. Robert Pearson, Microelectronic Engineering Program Director
Electrical and Microelectronic Engineering
82 Lomb Memorial Drive
Rochester, NY 14623
Phone (585) 475-2923
Email: robert.pearson@rit.edu
http://www.rit.edu/kgcoe/microelectronic

2 Master of Science in Electrical Engineering (EEEE-MS)

2.1 General Steps towards earning the MSEE Degree

- The MSEE Program requirements which is a total of 30 credits can be completed by one of the following options
    - Graduate Thesis (6 credit hours) and 8 courses (3 credits each)
    - Graduate Paper (s credit hours) and 9 courses (3 credits each)
    - Comprehensive Exam (No credit) and 10 courses (3 credits each)

  Details are provided in section 2.3.

- MSEE students are required to select a focus area prior to registering for their first semester of studies upon which a faculty advisor in that area will be assigned who will assist the student with course selections. The focus area, however, can be changed to meet educational needs. Details are provided in Section 2.4 and 2.6. The MSEE course outlines are provided in Appendix D.

- During the first semester, MSEE students should begin to consider a topic for their graduate paper or thesis. This document contains recent thesis titles as well as up to date abstracts of faculty publications in Appendices A, B, and K, which may assist you in determining a specific thesis or graduate paper advisor. While completing the remaining credits, students are encouraged to continue to develop their paper or thesis ideas and discuss their thoughts with their faculty advisor.

- Graduate thesis (6 credit) can be split in increments of 3 credits per semester. AFTER you have registered for all six credits, you must KEEP REGISTERING on a semester-by-semester-basis for one credit each time, for as long as your work is still in progress. This allows you to stay current in the system. You are allowed one free credit in which to complete your thesis. After that, you will be charged for one credit per semester until you complete your thesis. Summer semesters are free. Upon completion, students are required to obtain the proper approvals for their thesis and provide the necessary copies to the Electrical and Microelectronic Engineering department. Details are described in Section 2.11 and Section 5.

- Graduate paper (3 credits) needs to be completed in one semester, upon which a letter grade will be awarded by the faculty advisor. This grade will be counted for the cumulative grade point average (CGPA). Students are required to provide the necessary copies to the Electrical and Microelectronic Engineering department. Details are in Section 2.10 and Section 5.

- The Comprehensive exam is offered twice a year in January and June. Details are provided in section 2.12.

- During the semester prior to the one you intend to graduate in, you are required to complete and submit an application for graduation to the Electrical and Microelectronic Engineering department.

- Internships are permitted during any semester, upon approval of the graduate paper / thesis faculty advisor and the Graduate Program Director. Details are provided in Section 2.13.

2.2 Admission Requirements

Admission into graduate studies leading to an MS degree in Electrical Engineering requires a Bachelor of Science degree from an accredited program in Electrical Engineering (note that a BS degree in Microelectronic Engineering qualifies). An applicant with a strong undergraduate record and a Bachelor of Science degree in another branch of engineering (mechanical, computer, industrial, etc) will also be considered for admission. In this case, the student must complete a certain number of undergraduate courses in order to bridge over to Electrical Engineering. Additional information in this regard is available from the department.

A combined Bachelor of Science and Master of Science program in Electrical Engineering exists with separate admission requirements. Please refer to documents describing that program for admission requirements. These guidelines apply once a student has been accepted into the combined BS/MS EE program.

MSEE can be pursued both on a full time or part time basis.

2.3 Graduation Requirements

The Master of Science degree in Electrical Engineering is awarded upon the successful completion of an approved graduate program consisting of a minimum of 30 credit hours. Under certain circumstances, a student s required to complete more than the minimum number of credits.

2.4 Focus Areas of Specialization

For the MSEE degree, the student can select and specialize in one of the following eight areas.

- Control Systems
- Communications
- Digital Systems
- Electromagnetics, Microwaves and Antenna
- Integrated Electronics
- MEMS
- Robotics
- Signal & Image Processing

2.5 Graduate Student Advising

All incoming students will be assigned an academic faculty advisor who is in the focus area of their choice. He/she will continue to be the student's academic advisor until a research topic has been chosen. At that time, the thesis/paper advisor assumes the role of academic advisor.

2.6 Plan of Study and Policies

Every matriculated student must arrange to have a Plan of Study prepared in consultation with his/her faculty advisor *at the beginning of the program*

The following general rules apply to all MSEE students:

- All students seeking the MSEE degree must satisfactorily complete two core courses, EEEE-707: Engineering Analysis and EEEE-709: Advanced Engineering Mathematics. Students will be expected to take the required core courses immediately upon entering the program since these courses are prerequisites to several other graduate courses.

- Those students who have selected the following focus areas: Control Systems, Communications, Digital Systems, Electromagnetics, MEMS, Robotics and Signal & Image Processing, must also complete EEEE-602: Random Signals and Noise. Students who want to develop a minor in any of the above areas are also encouraged to take EEEE-602: Random Signals and Noise.

- Students must take three core courses from the Electrical and Microelectronic Engineering department in their chosen focus area and expected to perform the research needed for a graduate paper or thesis in the same area.

- Student may take the remaining courses from a related area within the College of Engineering, the Center for Imaging Science and the Computer Science Department with approval from the Graduate Program Director

- A maximum of 2 courses are allowed as electives from programs outside the above listed Colleges / Departments. These must be approved by the Graduate Program Director.

- The academic student advisor must approve all course selections. All courses must be 600 level or above.

- MSEE students scan select one of the following options to complete the degree requirement.

  - Graduate Thesis (6 credit hours) and 8 courses.

  - Graduate Research Paper (3 credit hours) and 9 courses.

  - Comprehensive Examination (NO Credit) and 10 courses.

- All graduate work must be completed within a seven-year period starting from the first course applied towards the MSEE degree. Also, a student who is pursuing the thesis/graduate paper options may be required to register for a continuation of thesis credits if he or she is not enrolled for any credits in a given semester. For complete details, please consult the Continuation of Thesis credit requirements discussed in the beginning section of the RIT Graduate Catalog.

2.7 Transfer Credits

For students transferring credits from other universities, a maximum 2 graduate courses (6 credits) are allowed with approval from the Graduate Program Director.

2.8 Graduate Teaching and Research Assistantships

The Electrical and Microelectronic Engineering Department offers teaching assistantships to a limited number of students during the student's first academic year of study. Subsequently, however, students are encouraged to seek support as research assistants (RA) from one of the research faculty. Full time graduate teaching assistant (TA) are awarded to limited number of outstanding incoming first year graduate students.

2.9 Good Academic Standing

A 3.0 GPA or higher is required to graduate. ALL graduate courses taken after matriculating into an MS program at RIT are counted toward your grade point average (GPA). To be in good academic standing, a graduate student must maintain a cumulative GPA of 3.0/4.0 or better throughout their program of study. Students would be placed on probation or may be suspended at the discretion of the Graduate Program Director and in accordance with RIT and KGCOE policies if the cumulative GPA falls below 3.0. If placed on probation, students are given one semester to elevate their GPA to 3.0 or be suspended indefinitely from the program. Please note that RIT institute policy states ‘C^{-}’, ‘D’ or ‘F’ grades do not count toward the fulfillment of the program requirements for a graduate degree.” However, they are calculated in the GPA and will remain on the student’s transcript permanently. Students placed on probation may have their scholarship reduced or totally eliminated at the discretion of the Graduate Program Director and in accordance with RIT policies.

2.10 MSEE Graduate Paper

The MSEE graduate paper is 3 credits. It is treated as a regular course that is required to be completed in one semester. Letter grades A through F will be assigned by the Faculty advisor. This grade will count towards the CGPA. Students are required to provide the necessary copies to the Electrical and Microelectronic Engineering department. Details of the format of the paper is given in Section 5.

2.11 MSEE Thesis

Graduate thesis (6 credits) can be split in increments of 3 credits per semester. AFTER you have registered for all six credits, you must KEEP REGISTERING on a semester-by-semester-basis for one credit each time, for as long as your work is still in progress. This allows you to stay current in the system. You are allowed one free credit in which to complete your thesis. After that, you will be charged for one credit per semester until you complete your thesis. Summer semesters are free. Upon completion, students are required to obtain the proper approvals for their thesis and provide the necessary copies to the Electrical and Microelectronic Engineering department. Details of the thesis defense and thesis format are provided in Section 5.

2.12 MSEE Comprehensive Exam

- There are two parts to the exam.
    - Part I: Based on the two Mandated Courses
        - EEEE707 Engineering Analysis
        - EEEE709 Advanced Engineering Mathematics
    - Part II: Based on the Student’s Focus Area

- Students are allowed to take the exam after a successful completion of 7 to 8 EE courses.

- The exam will be conducted twice every academic year: Mid-June and January (during the Intersession)
- Sign up for the exam is in early May and early December
- The duration of the exam is 3 to 5 hours.
- The exam is written, held in class and proctored.
- Part I is closed book.
- Part II is closed book or open book, depending on the focus area and the instructor.
- In case of a failing grade a maximum of two more attempts are permitted (total 3 attempts).

2.13 Policies for Graduate Co-op in the MSEE Program

Following is the approval process for internships.

- Student should have an offer letter from a company with start and end dates.
- Students should be registered for courses in the following semester.
- Students working on their graduate thesis will require approval by their faculty advisor.
- The approval from the faculty advisor should state the following in a written communication.
    - Title of graduate paper/thesis
    - Anticipated completion date
    - Endorsement by faculty that the internship will enhance the student's research
    - Commitment by the faculty that upon return of student to RIT, the faculty will continue to work with student to ensure that the graduate paper /thesis will be completed in a timely manner.
- Upon approval by the MSEE Program coordinator, the student will be registered in EEEE699-Graduate Co-op.
- Students accepted for internship by a company who fail to report for work will not be permitted to accept any other internship during their duration in the MSEE program at RIT.

2.12 Schedule of EE Graduate Course Offerings (600, 700 level) 2016 -2017

Core Courses	Fall 2016-1	Spring 2016-5
Required Courses for all focus areas	EEEE-707 Engineering Analysis EEEE-709 Adv. Engineering Mathematics	EEEE-707 Engineering Analysis EEEE-709 Adv. Engineering Mathematics
Required Courses for all Focus Areas except #5	EEEE-602 Random Signal and Noise	EEEE-602 Random Signal and Noise
Focus Area		
1 - Communication	EEEE-593/693 Digital Data Communication. EEEE-629 Antenna Theory and Design EEEE-718 Des & Characterization of Microwave Systems EEEE-793 Error Detect/Error Correction	EEEE 592/692 Communications Networks EEEE-594/694 Sensor Array Processing for Wireless Communications EEEE-617 Microwave Circuit Design EEEE-710 Advanced Electromagnetic Theory EEEE-794 Information Theory EEEE-797 Wireless Communication
2 - Control Systems	EEEE-661 Modern Control Theory EEEE-669 Fuzzy Logic & Applications	EEEE-765 Optimal Control EEEE-766 Multivariable Modeling
3 - Digital Systems	EEEE-520/620 Design of Digital Systems EEEE521/621 Design of Computer Systems	EEEE-520/620 Design of Digital Systems EEEE-720 Adv Topic in Digital Sys Design EEEE-721 Adv Topics in Computer Sys Design
4-Electromagnetics, Microwaves and Antenna	EEEE-629 Antenna Theory & Design EEEE-710 Advanced Electromagnetic Theory	EEEE-617 Microwave Circuit Design EEEE-718 Des & Characterization of Microwave Systems
5- Integrated Electronics	EEEE-510/610 Analog Electronics EEEE-711 Advanced Carrier-Injection Devices EEEE-713 Solid State Physics MCEE-601 Micro Fabrication	EEEE-712 Advanced Field Effect Devices EEEE-726 Mixed Signal IC Design (2nd year standing) MCEE-732 CMOS Mfg.
6-MEMS	EEEE-661 Modern Control Theory EEEE-689 Fundamentals of MEMs MCEE-601 Micro Fabrication MCEE-770 MEMs Fab	EEEE-786 Microfluidic MEMs EEEE-787 MEMs Evaluations
7- Robotics	EEEE 585/685 Principles of Robotics EEEE-547/ 647 Artificial Intelligence(2nd year standing) EEEE-661 Modern Control Theory	EEEE-536/636 Biorobotics/ Cybernetics EEEE-784 Advanced Robotics (2nd year standing)
8- Signal & Image Processing	EEEE-678Digital Signal Processing EEEE-779 Digital Image Processing	EEEE-670 Pattern Recognition EEEE-780 Digital Video Processing EEEE-781 Image and Video Compression

- A selected number of 500, 600 and 700 level courses are usually made available during the summer semester. Please consult the Electrical and Microelectronic Engineering Department for up to date course offerings.
- Graduate level courses taken in Microelectronic Engineering or Computer Engineering can be counted towards the four course requirement in the Digital Systems, Integrated Electronics or MEMs focus areas.
- Robust Control is offered on a yearly basis by either the EME or the Computer Engineering department. Either version is accepted for the control focus area.
- Pattern recognition is offered on a yearly basis by either the EME or the Imaging Science Department. Either version is accepted in the Signal Processing focus area.

3 Master of Science in Microelectronic Engineering (MCEE-MS)

3.1 General Steps towards earning the Degree

- Master of Science in Microelectronics students have a default schedule for their first semester, if a student has transfer credit or other academic issues they should meet with their initially assigned graduate advisor or the program director before registering for their first semester of studies.

- During the first semester, Master of Science students should begin to consider a topic for their graduate thesis. This document contains recent thesis titles as well as up to date abstracts of faculty publications which may assist you in determining a specific thesis advisor.

- While completing the remaining credits, students are encouraged to continue to develop their thesis ideas and discuss their thoughts with their faculty advisor.

- MCEE students can register for thesis (minimum of 6 credits) in increments of 3 credits per semester. AFTER you have registered for all six credits, you must KEEP REGISTERING on a semester-by-semester-basis for one credit each time, for as long as your work is still in progress. This allows you to stay current in the system. You are allowed one free credit in which to complete your thesis. After that, you will be charged for one credit per semester until you complete your thesis. Summer semesters are free. Upon completion, students are required to obtain the proper approvals for their thesis and provide the necessary copies to the Electrical and Microelectronic Engineering department.

- During the semester prior to the one you intend to graduate in, you are required to complete and submit an application for graduation to the Electrical and Microelectronic Engineering department.

- Master of Science students are required to obtain the proper approvals for their thesis and provide the necessary copies to the Electrical and Microelectronic Engineering department.

3.2 Admission Requirements

The objective of the Master of Science in Microelectronic Engineering program is to provide an opportunity for students to perform graduate level research as they prepare for entry into the semiconductor industry or a Ph.D. program. The program requires strong preparation in the area of microelectronics. The program typically takes two years to complete and requires a thesis. Applicants must hold a baccalaureate degree in Electrical Engineering, Chemical Engineering, Materials Science and Engineering, Physics or the equivalent, from an accredited college or university in good academic standing. An undergraduate grade point average of 3.0 or better on a 4.0 scale or strong academic advisor/supervisor endorsements are required. Graduate Record Exam (GRE) scores are not mandatory but may support the candidacy.

The prerequisites include a BS in engineering (such as electrical or microelectronic engineering), and an introductory course in device physics. Students from RIT's BS in microelectronic engineering meet these prerequisites. Students who do not have the prerequisite device physics can take a course during their first year of study at RIT and still complete the Master of Science program in two years. The prerequisite course will not count toward the 24 credits worth of graduate courses required for the MS degree.

3.3 Program

The program consists of eight graduate level (600 level or higher) courses, including six core courses and two elective courses for students with a BS degree in a discipline other than Microelectronic Engineering. Two core courses and six elective courses are required for students with BS in Microelectronic Engineering. In addition, all graduate students in this program are required to take one credit seminar/research course for three semesters. Up to 3 seminar/research credits will be allowed to count toward the required 33 hours. A six-credit thesis that includes dissertation submission and oral defense will be required of all students in this program. The total number of credits needed for the Master of Science in Microelectronics Engineering is 33.

3.4 Core Courses

MCEE-601	Micro Fabrication
MCEE-602	Semiconductor Process Integration
MCEE-603	Thin Films
MCEE-605	Lithographic Materials and Processes
MCEE-615*	Nanolithography Systems
MCEE-732	Microelectronic Manufacturing
MCEE-704**	Physical Modeling Semiconductor Devices

*Required for ME not MS
**Required for MS not ME

3.5 Elective Courses

The following elective courses are offered for graduate credits:

MCEE-706	SiGe and SOI Devices and Technology
MCEE-615*	Microlithography Systems, Lab
MCEE-620	Photovoltaics
MCEE-704**	Physical Modeling of Semi Devices
MCEE-732	Microelectronics Manufacturing
MCEE-730	Metrology Failure Analysis & Yield
MCEE-770	MEMS Fabrication
MCEE-789	Special Topics

*Required for ME elective for MS
**Required for MS elective for ME

Based on the student's particular needs, he or she may, with the approval of the program director, choose electives from other programs at RIT.

3.6 Plan of Study

The student - in consultation with his or her academic advisor - formulates a plan of study based on the student's academic background, program objectives, degree requirements and course offerings and submits it to the program director within the first year. The plan of study should be revised with the recommendation of the advisor at start of each semester in the second year of study.

3.7 Graduate Student Advising

Dr. Karl Hirschman is the initial advisor for students with a BS in Microelectronics.
Dr. Sean Rommel is the initial advisor for students with a BS in other engineering disciplines.

3.8 Assistantships and Fellowships

A limited number of assistantships and fellowships may be available for full-time students. Appointment as a teaching assistant typically carries a 10-12-hour-per-week commitment to a laboratory teaching function and permits a student to take graduate work at the rate of 10 credits per semester. Appointment as a research assistant also permits taking up to 10 credits per semester while the remaining time is devoted to the research effort, which often serves as a thesis subject. Students in the MS program are eligible for research fellowships. Appointments provide full or partial tuition and stipend. Applicants for financial aid should contact to the program director for details.

3.9 Thesis Proposal and Thesis Work

A process and set of requirements have been created for the thesis proposal for the Master of Science degree in Microelectronic Engineering. The thesis proposal should occur in the fall or early spring of the second year of MS study. Key features of the proposal are the make-up of the committee, the literature search, presentation of the problem/issues, research plan and thesis timetable. A copy of a sample proposal can be obtained to illustrate the proper format and content. The expectation of the Microelectronic Engineering program is that the master's thesis will involve an *empirical* component. While theoretical frameworks or conceptual models may (and should in many cases) guide the research questions, or be the subject of empirical testing, a strictly theoretical paper is <u>not</u> acceptable for a master's thesis. The thesis may involve research in device, circuit or process design, development and validation and evaluations through modeling and *analysis within the realm of microelectronic engineering discipline*.

In some cases, the thesis may be developed in conjunction with ongoing projects or extension of existing processes. In other cases, the thesis may involve original or new devices, circuits, and/or processes. The thesis may involve quantitative data, qualitative data, or a combination of both types of data. Details about the thesis defense, thesis preparation, binding etc. can be found in a later section of this document (section VII).

3.10 Typical Schedule for a non BS MicroE student

A *<u>typical</u>* schedule for a Master of Science in Microelectronic Engineering student where the student does *<u>not</u>* hold a BS in Microelectronic Engineering			
Fall (year 1)	**Spring (year 1)**	**Fall (year 2)**	**Spring (year 2)**
1. MCEE-601 Micro Fab, Lab **CORE** 2. MCEE-605 (3 cr) Microlithography Materials & Processes, Lab **CORE** 3. MCEE-603 (3 cr) Thin Films, Lab **CORE** 4. MCEE-794 (1 cr) Seminar/Research	1. MCEE-602 (3 cr) Semiconductor Process Integration **CORE** 2. MCEE-732 (4 cr) Microelectronic Manufacturing & Lab **CORE** 3. Graduate Professional Elective (3 cr) 4. MCEE-794 (1 cr) Seminar/Research	1. MCEE-704 (3 cr) Physical Modeling of Semi. Devices, Lab **CORE** 2. MCEE-790 (3 cr) Thesis 3. Graduate Professional Elective (3 cr) 4. MCEE-794 (1 cr) Seminar/Research	1. MCEE-790 (3 cr) Thesis 2. Full Time Equivalency (6 cr) Research
Total of 33 credits: 3 Seminar, 6 thesis and 24 course credits (8 courses). Transition courses may be required which do not count towards the degree credits.			

3.11 Typical Schedule for a BS MicroE student

A ***typical*** schedule for a Master of Science in Microelectronic Engineering student who already holds a BS in Microelectronic Engineering			
Fall (year 1)	**Spring (year 1)**	**Fall (year 2)**	**Spring (year 2)**
1. Graduate Professional Elective (3 cr) 2. Graduate Professional Elective (3 cr) 3. Graduate Professional Elective (3 cr) 4. MCEE-794 (1 cr) Seminar/Research	1. Graduate Professional Elective (3 cr) 2. MCEE-732 (3 cr)Microelectronic Manufacturing, Lab **CORE** 3. Graduate Professional Elective (3 cr) 4. MCEE-794 (1 cr) Seminar/Research	1. MCEE-704 (3 cr) Physical Modeling of Semi. Devices, Lab **CORE** 2. MCEE-790 (3 cr) Thesis 3. Graduate Professional Elective (3 cr) 4. MCEE-794 (1 cr) Seminar/Research	1. MCEE-790 (3 cr) Thesis 2. Full Time Equivalency (6 cr) Research
Total of 33 credits: 3 Seminar, 6 thesis and 24 course credits (8 courses).			

4 Master of Engineering in Microelectronic Manufacturing Engineering (MCEMANU-ME)

4.1 General Steps towards earning the Degree

- Master of Engineering in Microelectronics students should meet with the program director before the start of the first semester. Students will be automatically enrolled in the typical fall courses. If changes need to be made they can be done during the first week of the semester (add/drop).

- Master of Engineering students should begin to search for a company at which they can complete their internship. This should begin as early as the fall semester. They should register at the RIT Co-op and Placement office and begin the interview process.

- During the semester prior to the one you intend to graduate in, you are required to complete and submit an application for graduation to the Electrical and Microelectronic Engineering department.

4.2 Admission Requirements

The Master of Engineering in Microelectronics Manufacturing Engineering program offered by the department of Electrical and Microelectronic Engineering at Rochester Institute of Technology provides a broad based education to students with a bachelor's degree in traditional engineering or science disciplines interested in a career in the semiconductor industry. The GRE exam is not required but may give the admission committee additional insight into the candidates qualifications. A TOEFL score of 85 or greater is preferred.

4.3 Program Requirements

The Master of Engineering degree is awarded upon successful completion of an approved graduate program consisting of a minimum of 30 credit hours. The program consists of a possible transition course, six core courses, two elective courses, two credits of the research methods course and a minimum of 4 credits of internship. Under certain circumstances, a student may be required to complete more than the minimum number of credits. The transition course is in an area other than that in which the BS degree was earned. For example, a chemistry major may be required to take a two-course sequence in circuits and electronics. The core courses are divided into three areas, the first is microfabrication MCEE 601, 602 and 603; the second is microelectronics manufacturing MCEE 732, and the third is microlithography materials and processes (MCEE605) and microlithography systems MCEE 615 (see the typical course schedule listed below). The two elective courses are graduate-level courses in a microelectronics related field. Elective courses may be selected from a list that includes courses such as defect reduction and yield enhancement, semiconductor process and device modeling. See the program director for a more complete list of elective courses.

The program requires an internship, which is at least three months of full time successful work employment in the semiconductor industry or academia. The internship can be completed in industry or at RIT. Students must pay a reduced tuition for internship credits. It will involve an investigation or a study of a problem or process directly related to microelectronics manufacturing engineering. This is not a thesis but requires a report and completion of a survey at the end of the project. A sample internship report and format guide can be obtained from the Microelectronic Engineering Program Director.

4.4 Microelectronics

The Microelectronics sequence (MCEE 601, 602, 603) covers major aspects of integrated circuit manufacturing technology such as oxidation, diffusion, ion implantation, chemical vapor deposition, metallization, plasma etching, etc. These courses emphasize modeling and simulation techniques as well as hands-on laboratory verification of these processes. Students use special software tools for these processes. In the laboratory students design and fabricate silicon MOS integrated circuits. They learn how to utilize most of the semiconductor processing equipment and how to develop and create a process, manufacture and test their own integrated circuits.

4.5 Microlithography

The microlithography courses are advanced courses in the chemistry, physics and processing involved in microlithography. Optical lithography will be studied through diffraction, Fourier and image assessment techniques. Scalar diffraction models will be utilized to simulate aerial image formation and influences of imaging parameters. Positive and negative resist systems, as well as processes for IC application, will be studied. Advanced topics will include chemically amplified resists; multiple layer resist systems; phase shift masks, and electron beam, x-ray and deep UV lithography. Laboratory exercises include projection system design, resist materials characterization, process optimization, electron beam lithography and excimer laser lithography.

4.6 Manufacturing

The manufacturing course include topics such as scheduling, work-in-progress tracking, costing, inventory control, capital budgeting, productivity measures and personnel management. Concepts of quality and statistical process control are introduced to the students. The laboratory for this course is the student-run factory functioning in the department. Important issues that include measurement of yield, defect density, wafer mapping, control charts and other manufacturing measurement tools are introduced to the students in the lecture and laboratory. Computer integrated manufacturing is also studied in detail. Process modeling, simulation, direct control, computer networking, database systems, linking application programs, facility monitoring, expert systems applications for diagnosis and training and robotics are all introduced and supported by laboratory experiences in the integrated circuit factory at RIT. An online (distance delivery) version of this program exists for engineers employed in the semiconductor industry. Please refer to the RIT Part-time/Online Guide for details.

4.7 Typical Schedule

A *typical* schedule for a Master of Engineering in Microelectronic Manufacturing Engineering			
Fall (year 1)	**Spring (year 1)**	**Summer (year 1)**	**Fall (year 2)**
• MCEE-601 Micro Fab, Lab **CORE** • MCEE-605 (3 cr) Microlithography Materials & Processes, Lab **CORE** • MCEE-603 (3 cr) Thin Films, Lab **CORE** • MCEE-794 (1 cr) Seminar/Research	• MCEE-602 (3 cr) Semiconductor Process Integration **CORE** • MCEE-732 (4 cr) Microelectronic Manufacturing **CORE** • Graduate Elective (3 cr) • MCEE-794 (1 cr) Seminar/Research	• Internship (4 cr)	• Graduate elective (3 cr) • Graduate Professional Elective (3 cr)
Total of 30 credits: 2 Seminar, 4 internship and 24 course credits (8 courses). Transition courses may be required which do not count towards the degree credits.			

5 Graduate Paper and Thesis: Policies and Procedures for all EME Graduate Programs

5.1 Requirements

In order to obtain a Master of Science degree in Electrical Engineering, students must complete a Graduate Paper or a Graduate Thesis. Of the minimum 30 credit hours needed to earn the degree, a typical student earns 24 to 27 credit hours from course work and the remaining credit hours from the Paper or Thesis.

In order to obtain a Master of Science degree in Microelectronic Engineering students must complete a Graduate Thesis. Of the minimum 33 credit hours needed to earn the degree, a typical student earns 27 credit hours from course work and the remaining credit hours from the Thesis.

Thesis credits do not affect the GPA. A grade of 'R' is given upon registration. At completion, the advisor approves the paper with his or her signature.

5.2 Registration

If you are registering for a Graduate Paper, register for course EEEE-792, Section 1, the same way you would register for a course. If you are registering for a Thesis, register for EEEE-790 Section 1 (or MCEE-790 section 1 for Microelectronics Masters students). The Graduate Paper mandates a minimum of 3 credits while the Thesis requires 6 credits. You may register for these all at once or by increments of 1 credit.

NOTE: If you register for your Paper or Thesis one credit at a time, you will only be charged for one credit. . If you register for the total amount of credits all at once, you will be charged for the total amount of credits and will have only two semesters to complete the Paper or Thesis. After you register for the three credits allotted for the graduate paper, you are allowed 1 free semester in which you can register for EEEE-796: Continuation of Graduate Paper. You register for 1 or 0 credit hours. Note Microelectronics Masters students will follow the same procedure except that the course number will be MCEE-791.

After this free semester, if you are still not done with your paper, you must register for EEEE-796: Continuation of Graduate Paper for 1 or 0 credit hours. You will be charged for one credit hour. You are not charged for summer semesters. Always register for EEEE-796: Continuation of Graduate Paper after you have already registered for your three credits and have not completed your paper. This is to ensure that you stay in the system. Once your work has been completed and your Thesis/Paper is approved and accepted, the Electrical and Microelectronic Engineering department will certify you for graduation internally, provided all other graduate requirements have been met.

5.3 Procedures

When to Start? The most advantageous time to start thinking about the research work is when you have completed about two thirds of the course work. Planning for the thesis, however, should begin as early as possible. Normally, full-time students should complete all their degree requirements, including thesis defense, within 2 years (four academic semesters and one summer) from the date of entry.

Your thesis is the culmination of your graduate work and an opportunity to apply the knowledge and skills that you have acquired through course work and research assistantships, etc. It is intended as a guided, constructive learning experience. It is an opportunity for you to work in collaboration with a number of faculty members on a research project of mutual interest and to publish manuscripts resulting from the thesis.

How to Get Started? First, you need to explore possible topics and areas of mutual interest through talking with faculty members and reading the relevant published literature. You may become interested in certain areas as a result of course topics or papers. Your advisor or other faculty members may describe research projects they are currently working on that you might be interested in. *Since the masters degree time line is quite short, it is important to start exploring and discussing possible thesis topics as early as possible, no later than the end of the first year of the program for full-time students*. While students often conduct their thesis research in conjunction with their academic advisor (who then becomes their thesis supervisor), this is not always the case. There are many factors that influence the choice of thesis topics and the selection of a supervisor, including: mutual interest, projected costs and time line for the research, faculty availability during the anticipated thesis period, and a comfortable working relationship. You may not always be able to do exactly what you want to do; however, every attempt is made to match student and faculty interests. Faculty members may discourage ideas that are not suitable or feasible for a master's thesis. They are trying to assist you in choosing a project that is within your capabilities and available facilities and can be completed in a timely manner.

Thus, the initiation of ideas for possible thesis can come from either the student or from faculty members. You can bounce ideas off various faculty members, but you should keep your academic advisor appraised. Once an agreement is reached, in principle, to pursue a specific topic (on the part of both the student and a faculty member), you are ready to proceed to the proposal and committee selection phase of the process.

Who is on the Master's thesis committee? RIT guidelines stipulate that for degree programs requiring a Master's thesis, the committee must consist of three faculty members: *the supervisor from within the home department, and two committee members (at least one of whom has an academic appointment in the home department).* Your supervisor will assist you in selecting and approaching potential committee members for your thesis.

Once your thesis topic has been determined and your committee has been chosen, you can proceed with the development of the thesis proposal. You need to complete the *Declaration of Topic and Committee Form*, have it signed by your thesis supervisor, and return it to the Department Office. If you have a topic that you would like to explore, please give the office a call. We will match you with a professor who has similar interests. Before approaching the professor, prepare a one to two page summary of your ideas. This can be presented to the professor.

Upon mutual agreement on the topic and the scope of your work, the professor becomes your advisor. If you do not have a firm idea about a topic, please call us; we will be able to arrange a professor to talk to you. The professor may have a research topic that you could be interested in.

5.4 Graduate Paper: Format and Formalities

You must write a final report describing your research work. The Graduate Paper differs from the Thesis mostly in formatting requirements. It must be printed double-spaced on one side of a standard 8-1/2 x 11 sheet of paper. You are encouraged to bind the document. The final document need not be leather bound, but should have a soft binding (Comb Binding is available at the Hub Crossroads). A copy is not kept in the library.

You must work out a plan for frequent interactions and consultations with your advisor during the course of the research. A document generated without such consultation faces almost certain rejection.

What Are The Formalities?

The Graduate Paper is complete when your advisor approves it. A Paper, unlike a Thesis, need not be approved by a faculty committee; the Advisor alone approves or disapproves the paper. He or she may ask you to give a presentation before faculty and students or may simply accept the written document. The final copy must also be signed by the Department Head.

How Many Copies?

One copy of the final document, signed by your advisor and department head, must be submitted to the Electrical Engineering office. Your advisor and you should each retain a copy as well. Thus, the minimum number of copies is three though your supervisor at work or colleagues may want a copy as well.

5.5 Graduate Thesis

The candidate must select the subject of the Thesis in consultation with a faculty member who agrees to act as the Thesis advisor. The candidate must report the subject of the Thesis and the name of his advisor to the graduate-committee chairman.

5.5.1 Thesis Format

- The default style format for your thesis is the *Chicago Manual of Style*. Your thesis must meet the minimum requirements for correct sentence structure, spelling, punctuation and technical accuracy.
- The Library requests that you leave a margin of 1 inch on all sides of the paper to accommodate the bindery process.
- The thesis should be 1.5 or double-spaced. Footnotes and long quotations should be single-spaced.
- The font style must be a serif style-serif fonts have additional structural details that enhance the readability of printed text. One popular serif font is *Times New Roman*
- Font size must be no smaller than 10-point or larger than 12-point.
- All preliminary pages should be numbered with Roman numerals.
- The main text, illustrations, appendices and bibliography should use Arabic numbering.

5.5.2 Presentation to Committee (Thesis Defense)

The advisor for the Masters candidate submits the final thesis to a Faculty Committee for examination and approval. This committee is appointed by the thesis advisor and consists of three members of the graduate committee of the Department of Electrical and Microelectronic Engineering. Its approval is indicated by signatures on the title page of the original and the two required copies of the thesis.

The thesis must be defended and accepted in final form at least 30 days before the completion of the semester in which it is expected the degree will be conferred. The original and two copies must be given to the Department Office after signed approval by the student's advisor. Two of these copies are for transmittal to the Institute Library and one to the faculty advisor.

Notification of Thesis Defense: At least a week prior to the actual defense dates an electronic thesis defense notification email must be distributed to the EME faculty, staff and graduate students. This is done by supplying the graduate staff coordinator with a one page copy of the defense announcement. The title, date, location, student's name and advisor's name must appear along with an abstract of the defense

5.5.4 Permissions, Copyright, & Embargoes Permissions

Permission statements are no longer required.
Copyright:
Your work is automatically copyrighted once written. If you wish to add another layer of protection, you may register your work with the U.S. Copyright Office directly (http://www.copycerts@loc.gov). There are fees associated with this service. You also have the option for ProQuest to file for copyright with the U.S. Copyright Office on your behalf for a $55 fee. For more information on copyright, see:
http://www.proquest.com/documents/copyright_dissthesis_ownership.html.

Embargoes:
Any student who desires an embargoed thesis must make a request through the Office of Graduate Education. Contact the Office of Graduate Education at (585) 475-2127 OR bdogs@rit.edu for more information.

The Thesis/Dissertation Author Limited Embargo Notification form must be completed. This form states that an embargo has been approved by the Office of Graduate Education: http://infoguides.rit.edu/ld.php?content_id=15221363

5.5.5 Preparation of the Thesis for Binding

Your thesis should include the following:

The paper for RIT Archives copy must be 100% cotton bond (acid-free).

- **The title page** Title
- Author's name
- Type of degree
- Name of department and college
- Date approved: month, day, year

Committee Signature page

- The printed names and signatures of the committee members
- The thesis must be signed and dated by the Department Chair and/or your Graduate Advisor before binding takes place.
- An unsigned thesis will not be processed.

Abstract

The abstract should summarize the entire manuscript and its arguments for readers. It should be a single typed page, approximately 300 words.

Binding Reminders

- The paper for RIT Archives copy must be 100%, cotton bond (acid free paper).
- Your thesis/dissertation must be signed and dated by your Department Chair and/or your Graduate Advisor before it may be bound. An unsigned thesis/dissertation will not be accepted for binding.
- You are responsible for making copies of your thesis for binding.
- Collate, separate and clearly identify each copy before you bring them to the Library.

How to get your Thesis Bound

Thesis binding hours are **by appointment only** during the hours of 9am - 3:30pm. For appointment scheduling call Diane Grabowski 585-475-2554 or Tracey Melville 585- 475-6013 or schedule an appointment online.

Bring the following to the Thesis Dept at the Wallace Center; level A-500 when dropping off your thesis/dissertation for binding:

- 1 copy of your thesis/dissertation is required for the RIT Archives (Library).
- Copy/copies of your thesis/dissertation for yourself.
- Copy/copies of your thesis/dissertation for your department.
- Paid receipts (1 pink, 1 white) from the Student Financial Services.
- You are responsible for paying the binding fee for any copies other than the
- RIT Archives copy and those that are paid for by your department.
- The current binding fee is $14.00 per copy. The Library pays for the binding of its copy. The binding fee(s) must be paid at the Student Financial Services.
- Slides and CD-ROMS (optional)
- Slides are bound with the thesis/dissertation. All slides must be placed in a slide preserver sheet (provided by student).
- CD-ROMS are placed in back with an adhesive pocket (provided by student) when returned from the bindery.
- Name, phone number, or e-mail of individual picking up your copies.

Binding Process

Submit your thesis/dissertation to ProQuest at www.etdadmin.com/rit following these submission guidelines. A PDF version of your thesis must be submitted to ProQuest. Remember to exclude signatures from the electronic version of your paper. If you have any questions about the submission process, please call Jennifer Roeszies at (585) 475-2560 or email at etdlip@rit.edu.

NOTE: THE ELECTRICAL AND MICROELECTRONIC ENGINEERING OFFICE HAS COPIES OF ACCEPTED THESIS AND GRADUATE PAPERS. YOU ARE ENCOURAGED TO CONSULT THESE DURING THE COURSE OF YOUR WORK.

Appendix A: Electrical and Microelectronic Engineering Department Faculty

Mustafa A. G. Abushagur, Ph.D., California Institute of Technology, President of RIT Dubai. optical communications, computing, interconnects, MEMS, and optical signal processing, fiber bragg grating and sensors.

Vincent Amuso, PhD., Rensselaer Polytechnic Institute, Senior Lecturer, Communications, Radar and Signal Processing

David Borkholder, Ph.D., Stanford University, Professor, biosensors (electromagnetic and chemical), biomedical Instrumentation, MEMs fabrication, systems engineering

Edward Brown, Ph.D., Vanderbilt University, Associate Professor, rehabilitation, robotics, control systems, biomechatronics

Sohail A. Dianat, Ph.D., George Washington University, Professor and Department Head, control systems, communications, signal/ Image processing

Dale E. Ewbank, Ph.D., Rochester Institute of Technology, Senior Lecturer, microlithography and electro-optics.

Lynn F. Fuller, Ph.D., State University of New York at Buffalo, Professor, IEEE Fellow, Microsystems MEMS (micro-electro-mechanical systems) with integrated CMOS electronics (digital and analog) for a wide variety of applications including biomedical and remote sensing.

Luis Herrera, PhD., Ohio State University, Assistant Professor, power electronics, smart grid, renewable energy integration (solar, wind), and their related control strategies

Karl D. Hirschman, Ph.D., University of Rochester, Professor, integration of novel device structures (e.g. sensors, optoelectronic devices) with silicon microelectronics, and the integration of silicon devices with non-traditional substrates.

Christopher Hoople, Ph.D., Cornell University, Senior Lecturer, power electronics, device physics

Mark Hopkins, Ph.D., Virginia Polytechnic, Professor, control systems, system identification

Michael A. Jackson, Ph.D., State University of New York at Buffalo, Associate Professor, photovoltaics, defect analysis and metrology, thin film processes, optics and fields.

Mehran Mozaffari Kermani, Ph.D., Western University, London, Ontario Canada, Assistant Professor, cryptographic hardware architectures, embedded systems security, reliable and secure low-power FPGA and ASIC designs, and fault diagnosis and tolerance in VLSI crypto-systems.

Santosh K. Kurinec, Ph.D. in Physics, University of Delhi – India, Professor, photovoltaics, novel materials, device integration, tunnel diodes, magnetic tunnel junctions (MTJ), magnetic materials and devices, silicon-carbide devices.

Sergey Lyshevski, Ph.D., Kiev, Polytechnic Institute, Professor, microsystems

Panos P. Markopoulos, Ph.D., University at Buffalo, Assistant professor, communication and signal processing

James Moon, Ph.D., University of California at Berkeley, Professor, solid state devices, VLSI Design, semiconductor physics, integrated circuit design, electronic & photographic imaging systems

Sildomar Takahashi Monteiro, Ph.D., Tokyo Institute of Technology, Tokyo, Japan, Assistant Professor, robotics, machine learning, statistical signal and image processing, remote sensing, biomedical imaging.

P.R. Mukund, Ph.D., University of Tennessee, Professor, VLSI design, analog circuit design and electronics packaging

Dorin Patru, Ph.D., Washington State University, Associate Professor, mixed-signal and digital integrated circuits

Robert E. Pearson, Ph.D., State University of New York at Buffalo, Associate Professor, device physics, semiconductor processing, device simulation, electrical testing and characterization.

Daniel Phillips, Ph.D., University of Rochester, Associate Professor, biomedical instrumentation, signal processing & visualization, and embedded systems.

Ivan Puchades, Ph.D., Rochester Institute of Technology, Assistant Professor, MEM's, micro-fabrication, circuits and sensors.

Sean L. Rommel, Ph.D., University of Delaware, Professor, nanoelectronic devices and circuits, photonic/optoelectronic devices/circuits, and advanced semiconductor fabrication techniques. Specializes in experimental demonstration of tunneling devices.

Eli S. Saber, Ph.D., University of Rochester, Professor, signal, image & video processing communications, biomedical, computer vision

Ferat Sahin, Ph.D., Virginia Polytechnic Institute, Professor, robotics, artificial intelligence, control systems

George B. Slack, BS, Rochester Institute of Technology; MS, University of Rochester— Senior Lecturer

Gill Tsouri, Ph.D., Ben-Gurion University, Associate Professor, digital and wireless communications, signal processing for biomedical applications

Jayanti Venkataraman, Ph.D., Indian Institute of Science, Bangalore, India, - Professor, Electromagnetics, theoretical modeling and measurement of microstrip antennas and integrated microwave circuits, CRHL transmission line metamaterials and applications, Bbioelectromagnetics.

Jing Zhang, BS, Huazhong University of Science and Technology (China), Ph.D., Lehigh University, Assistant Professor, Various aspects of computational/advanced simulations, MOCVD growths (epitaxy), and device fabrication of III-Nitride semiconductors for photonics, thermoelectric, and solid state lighting applications.

Appendix B: Recent Electrical Engineering Research Thesis Titles

DATE	AUTHOR	TITLE	ADVISOR
2016	Sandeep Aswath Narayana	An Artificial Neural Networks based Temperature Prediction Framework for Network-on-Chip- based Multicore Platform	Dr. Ganguly
2016	Sriram Kumar	Learning Robust and Discriminative Manifold Representations for Pattern Recognition	Dr. Savakis
2016	Miguel Dominguez	Structure-Constrained Basis Pursuit for Compressively Sensing Speech	Dr. Ghoraani
2016	Raul Mittmann Reis	A New Model-Free Sliding Mode Control Method with Estimation of Control Input Error	Dr. Crassidis
2015	Prasanth Ganesan	Characterization of Cardiac Electrogram Signals During Atrial Fibrillation	Dr. Ghoraani
2015	Sulabh Kumra	Robot Learning Dual-Arm Manipulation Tasks by Trial-and Error and Multiple Human Demonstrations	Dr. Sahin
2015	Chen Chen	A Wireless Communication Platform for MEMs Sensors	Dr. Fuller
2015	Kwadwo Opong Mensah	Pulsar:Design and Simulation Methodology for Dynamic Bandwidth Allocation in Photonic Network-on-Chip Architectures in Heterogeneous Multicore Systems	Dr. Ganguly
2015	Celal Savur	American Sign Language Recognition System by Using Surface EMG Signal	Dr. Sahin
2015	Supachan Traitruengsakul	Automatic Localization of Epileptic Spikes in EEGs of Children with Infantile Spasms	Dr. Ghoraani
2015	Trevor Smith	Design and Analysis of High Frequency Power Converters for Envelope Tracking Applications	Dr. Lyshevski
2015	Siyu Zhu	An End-To-End License Plate Localization and Recognition System	Dr. Dianat
2015	James Mazza	Software/Hardware Tradeoffs in the Speedup of Color Image Processing Algorithms	Dr. Patru
2015	Evan Jorgensen	Design of VCOs in Deep Sub-Micron Technologies	Dr. Mukund
2015	Abdullah Zyarah	Design and Analysis of a Reconfigurable Hierarchical Temporal Memory Architecture	Dr. Kudithipudi
2015	Aaron Wilbee	A Framework for Learning Scene Independent Edge Detection	Dr. Sahin
2015	Jonathan Zimmermann	Frequency Constraints on D.C. Biasing in Deep Submicron Technologies	Dr. Mukund
2014	Christopher Johnson	Omnidirectional control of the Hexapod Robot TigerBug	Dr. Sahin
2014	Kai Tian	Fault-Resilient Lightweight Cryptographic Block Ciphers for Secure Embedded Systems	Dr. Kermani
2014	Kyle Tomsic	Analysis of the Effects of Pre-and Post-Processing Methods on vPPG	Dr. Tsouri
2014	Christopher Torbitt	Antenna Gain Enhancement and Beamshaping using a Diffractive Optical Element (DOE)Lens	Dr. Venkataraman
2014	Daniel Sinkiewicz	A Novel Method for Extraction of Neural Response from Cochlear Implant Auditory Evoked Potentials	Dr. Ghoraani
2014	Shitij Kumar	A Brain Computer Interface for Interactive and Intelligent Image Search and Retrieval	Dr. Sahin
2014	Chandan Amareshbabu	Modeling, Simulation and Fabrication of 100nn (Leff) High Performance CMOS Transistors	Dr. Fuller
2014	Michael Ostertag	Reconstructing Electrocardiogram Leads from a Reduced Lead Set through the use of Patient-Specific Transforms and Independent Compnent Analysis	Dr. Tsouri
2014	Hanfeng Wang	Switched-Capacitor Voltage Double Design Using 0.5 am Technology	Dr. Bowman
2014	Andrew Phillips	A Study of Advanced Modern Control Techniques Applied To a twin Rotor MIMO System	Dr. Sahin
2014	Jamison Whitesell	Design for Implementation of Image Processing Algorithms	Dr. Patru
2014	Steven Ladavich	An Atrial Activity Based Algorithm for the Single-Beat Rate-Independent Detection of Atrial Fibrillation	Dr. Ghoraani
2013	Girish Chandrashekar	Fault Analysis Using State-of-the-Art Classifiers	Dr. Sahin
2013	Matt De Capua	Current Sensing Feedback for Humanoid Stability	Dr. Sahin
2013	Kevin Fronczak	Stability Analysis of Switched DC-DC Boost Converters for Integrated Circuits	Dr. Bowman
2013	Matthew Ryan	FPGA Hardware Accelerators-Case Study on Design Methodologies and Trade Offs	Dr. Lukowiak
2013	Survi Kyal	Constrained Independent Component Analysis for Non-Obtrusive Pulse Rate Measurements Using a Webcam	Dr. Tsouri
2013	Matthew Sidley	Calibration for Real-Time Non-Invasive Blood Glucose Monitoring	Dr. Venkataraman

Appendix C: Recent Microelectronic Research ThesisTitles

DATE	AUTHOR	TITLE	ADVISOR
2016	Kavya Duggimpudi	Characterization of Grid contacts for n-Si Emitter Solar Cells	Dr. Jackson
2015	Joshua Locke	CMOS Compatible 3-Axix Magnetic Field Sensor using Hall Effect Sensing	Dr. Fuller
2015	Karine Florent	Ferroelectric Hf02 for Emerging Ferroelctric Semiconductor Devices	Dr. Kurinec
2015	Anusha Aithal	Wireless Sensor Platform for Pulse Oximetry	Dr. Fuller
2015	Matthew Filmer	InAs/GaSb Tunnel Diodes	Dr. Rommel
2015	Abhinav Gaur	Surface Treatments to Reduce Leakage Current in Homojunction in 0:53Gao:47 asPin Diodes for TFET Applications	Dr. Rommel
2015	Joshua Melnick	Aluminum Nitride Contour Mode Resonators	Dr. Puchades
2014	Anthony Schepis	Alternative Lithographic Methods for Variable Aspect Ration Vias	Dr. Smith
2014	David Cabrera	Material Engineering for Phase Change Memory	Dr. Kurinec
2014	Idris Smaili	Design and Simulation of Short Channel Ferroelectric Field Effect Transistor	Dr. Kurinec
2014	Nathaniel Walsh	Passivation of Amorphous Indium-Gallium-Zinc Oxide (IGZO) Thin-Film Transistor	Dr. Hirschman
2014	Samarth Parikh	Manufacturing Design and Fabrication of 100 mm(leff)CMOS Devices	Dr. Pearson
2014	Christopher Maloney	Compensation of Extreme Ultraviolet Lithography Image Field Edge Effects Through Optical Proximity Correction	Dr. Pearson
2013	Brian Romanczyck	Fabrication and Characterization of III-V Tunnel Field-Effect Transistors for Low Voltage Logic Applications	Dr. Rommel
2013	Qinglong Li	Investigation on Solid-Phase Crystallization (SPC) techniques for low-temperature poly-Si thin-film transistor applications	Dr. Hirschman
2013	Seth Slavin	Thermal & Electrical Simulation for the Development of Solid-Phase Polycrystalline Silicon TFT's	Dr. Hirschman
2013	Nan Xiao	Thin-Film Transistors Fabricated Using Sputter Deposition of ZnO	Dr. Hirschman
2013	Ketan Deshpande	Simulation and Implementation of Moth-eye Structures as a Broadband Anti-Reflective Layer	Dr. Ewbank
2013	Shaurya Kumar	Investigation of Bolometric and Resistive Properties of Nickel Oxide	Dr. Fuller
2012	Daniel Smith	Multi-Sensor MEMS for Temperature, Relative Humidity, and High-G Shock Monitoring	Dr. Fuller
2012	Lydia Alvarez-Camacho	Fabrication of Jet Printed Interdigitated Back Contact Solar Cells	Dr. Pearson
2012	Shaoting Hu	Exploring Si/SiGe Quantum-Well Thin-Film Thermoelectric Devices using TCAD Simulation	Dr. Hirschman

Appendix D: Electrical Engineering (MSEE) Graduate Course Descriptions

EEEE- 602 Random Signals & Noise
In this course the student is introduced to random variables and stochastic processes. Topics covered are probability theory, conditional probability and Bayes theorem, discrete and continuous random variables, distribution and density functions, moments and characteristic functions, functions of one and several random variables, Gaussian random variables and the central limit theorem, estimation theory , random processes, stationarity and ergodicity, auto correlation, cross-correlation and power spectrum density, response of linear prediction, Wiener filtering, elements of detection, matched filters. (Graduate Standing) Class 3, Lab 0, Credit 3 (F, S)

EEEE-605 Modern Optics for Engineers
This course provides a broad overview of modern optics in preparation for more advanced courses in the rapidly developing fields of optical fiber communications, image processing, super-resolution imaging, optical properties of materials, and novel optical materials. Topics covered: geometrical optics, propagation of light, diffraction, interferometry, Fourier optics, optical properties of materials, polarization and liquid crystals, and fiber optics. In all topics, light will be viewed as signals that carry information (data) in the time or spatial domain. After taking this course, the students should have a firm foundation in classical optics. (EEEE-473) Class3, Credit 3 (S) Class 3, Lab 0, Credit 3 (Fall or Spring)

EEEE-610 Analog Electronics
This is a foundation course in analog integrated electronic circuit design and is a perquisite for the graduate courses in analog integrated circuit design EEEE-726 and EEEE-730. The course covers the following topics: (1)CMOS Technology (2) CMOS active and passive element models (3) Noise mechanisms and circuit noise analysis (4) Current mirrors (5) Differential amplifiers, cascade amplifiers (6) Multistage amps and common mode feedback (7) Stability analysis of feedback amplifiers; (8) Advanced current mirrors, amplifiers, and comparators (9) Band gap and translinear cells (10) Matching. (EEEE-482 Electronics II or equivalent background, or Graduate Standing) Class 2, Lab 3, Credit 3 (F)

EEEE-617 Microwave Circuit Design
The primary objective is to study the fundamentals of microwave engineering with emphasis on microwave network analysis and circuit design. Topics include microwave transmission lines such as wave-guides, coax, microstrip and stripline, microwave circuit theory such as S- matrix, ABCD matrices, and even odd mode analysis, analysis and design of passive circuits and components, matching networks, microwave resonators and filters. Microwave circuit design projects will be performed using Ansoft's Designer software. (EEEE-374) Class 3, Lab 0, Credit 3 (S)

EEEE-620 Design of Digital Systems
The purpose of this course is to expose students to complete, custom design of a CMOS digital system. It emphasizes equally analytical and CAD based design methodologies, starting at the highest level of abstraction (RTL, front-end)), and down to the physical implementation level (back-end). In the lab students learn how to capture a design using both schematic and hardware description languages, how to synthesize a design, and how to custom layout a design. Testing, debugging, and verification strategies are formally introduced in the lecture, and practically applied in the lab projects. Students are further required to choose a research topic in the area of digital systems, perform bibliographic research, and write a research paper following a prescribed format. (EEEE-420 or equivalent background or Graduate Standing) Class 3, Lab 3, Credit 3 (F)

EEEE-621 Design of Computer Systems
The purpose of this course is to expose students to the design of single and multicore computer systems. The lectures cover the design principles of instructions set architectures, non-pipelined data paths, control unit, pipelined data paths, hierarchical memory (cache), and multicore processors. The design constraints and the interdependencies of computer systems building blocks are being presented. The operation of single core, multicore, vector, VLIW, and EPIC processors is explained. In the first half of the semester, the lab projects enforce the material presented in the lectures through the design and physical emulation of a pipelined, single core processor. This is then being used in the second half of the semester to create a

multicore computer system. The importance of hardware/software co-design is emphasized throughout the course. Students are further required to choose a research topic in the area of computer systems, perform bibliographic research, and write a research paper following a prescribed format. (EEEE-420 or equivalent background or Graduate Standing) Class 3, Lab 3, Credit 3 (F)

EEEE-629 Antenna Theory
The primary objective is to study the fundamental principles of antenna theory applied to the analysis and design of antenna elements and arrays including synthesis techniques and matching techniques. Topics include antenna parameters, linear antennas, array theory, wire antennas, microstrip antennas, antenna synthesis, aperture antennas and reflector antennas. A significant portion of the course involves design projects using some commercial EM software such as Ansoft Designer, Ansoft HFSS and SONNET and developing Matlab codes from theory for antenna synthesis and antenna array design. The measurement of antenna input and radiation characteristics will be demonstrated with the use of network analyzers, and spectrum analyzers in an anechoic chamber. (EEEE-374) Class 3, Lab 0, Credit 3 (F)

EEEE-636 Biorobotics/Cybernetics
Cybernetics refers to the science of communication and control theory that is concerned especially with the comparative study of automatic control systems (as in the nervous system and brain and mechanical-electrical communications systems). This course will present material related to the study of cybernetics as well as the aspects of robotics and controls associated with applications of a biological nature. Topics will also include the study of various paradigms and computational methods that can be utilized to achieve the successful integration of robotic mechanisms in a biological setting. Successful participation in the course will entail completion of at least one project involving incorporation of these techniques in a biomedical application. Students are required to write an IEEE conference paper on their projects. (Graduate Standing) Class 3, Lab 0, Credit 3 (S)

EEEE-647 Artificial Intelligence Explorations
The course will start with the history of artificial intelligence and its development over the years. There have been many attempts to define and generate artificial intelligence. As a result of these attempts, many artificial intelligence techniques have been developed and applied to solve real life problems. This course will explore variety of artificial intelligence techniques, and their applications and limitations. Some of the AI techniques to be covered in this course are intelligent agents, problem-solving, knowledge and reasoning, uncertainty, decision making, learning (Neural networks and Bayesian networks), reinforcement learning, swarm intelligence, Genetic algorithms, particle swarm optimization, applications in robotics, controls, and communications. Students are expected to have any of the following programming skills listed above. Students will write an IEEE conference paper. (Graduate Standing) Class 3, Lab 0, Credit 3 (F)

EEEE-661 Modern Control Theory
This course deals with a complete description of physical systems its analysis and design of controllers to achieve desired performance. The emphasis in the course will be on continuous linear systems. Major topics are: state space representation of physical systems, similarities/differences between input-output representation (transfer function) and state spate representations, conversion of one form to the other, minimal realization, solution of state equations, controllability, observability, design of control systems for desired performance, state feedback, observers and their realizations. (co-requisite: EEEE-707 Engineering Analysis Class 3, Lab 0, Credit 3 (F)

EEEE-663 Real-Time & Embedded Systems
This first course in a graduate elective sequence will begin by presenting a general road map of real-time and embedded systems. The course will be conducted in a studio class/lab format with lecture material interspersed with laboratory work. This course will introduce a representative family of microcontrollers that will exemplify unique positive features as well as limitations of microcontrollers in embedded and real-time systems. These microcontrollers will then be used as external, independent performance monitors of more complex real-time systems. The majority of the course will present material on a commercial real-time operating system and using it for programming projects on development systems and embedded target systems. Some fundamental material on real-time operating systems and multiprocessor considerations for

real-time systems will also be presented. Examples include scheduling algorithms, priority inversion, and hardware-software co-design. (Graduate Standing) Class 3, Lab 0, Credit 3 (F)

EEEE-664 Performance Engineering of Real Time and Embedded Systems
This course discusses issues of performance in real-time and embedded systems. Techniques for profiling the resource usage of a system and for measuring the effect of increasing system requirements will be covered. The control of physical systems will motivate the need for performance tuning of a real-time system. Students will write programs running under a real-time operating system that can maintain control of a physical system. The course will discuss and experiment with performance trade-offs that can be made using hardware-software co-design. (EEEE-663 or equivalent) Class 3, Lab 0, Credit 3 (F, S)

EEEE-665 Modeling of Real Time Systems
This course introduces the modeling of real-time software systems. It takes an engineering approach to the design of these systems by analyzing system models before beginning implementation. UML will be the primary modeling methodology. Non-UML methodologies will also be discussed. Implementations of real-time systems will be developed manually from the models and using automated tools to generate the code. (EEEE-663 or equivalent) Class 3, Lab 0, Credit 3 (F, S)

EEEE-669 Fuzzy Logic & Applications
In this course students are introduced to fuzzy systems and their applications in areas like control systems, signal and image processing, communications etc. Major topics are: Fuzzy sets and set operations, Evaluations of the rule sets using different implications, composition, aggregation and defuzzification methods. Applications in control systems: Development of fuzzy logic controllers for both linear and nonlinear systems & analysis and simulation studies of the designed systems. Function approximation using fuzzy systems. Students are also required to search published research works in other application areas like signal/image processing, communication, pattern recognition etc. and present their results to the class. (EEEE-414 or equivalent) Class 3, Lab 0, Credit 3 (F)

EEEE-670 Pattern Recognition
This course provides a rigorous introduction to the principles and applications of pattern recognition. The topics covered include maximum likelihood, maximum a posteriori probability, Bayesian decision theory, nearest-neighbor techniques, linear discriminant functions, and clustering. Parameter estimation and supervised learning as well as principles of feature selection, generation and extraction techniques, and utilization of neural nets are included. Applications to face recognition, classification, segmentation, etc. are discussed throughout the course. (EEEE-602, EEEE-707, EEEE-709) Class 3, Lab 0, Credit 3 (S)

EEEE-678 Digital Signal Processing
In this course, the student is introduced to the concept of multi rate signal processing, Poly phase Decomposition, Transform Analysis, Filter Design with emphasis on Linear Phase Response, and Discrete Fourier Transforms. Topics covered are: Z- Transforms, Sampling, Transform Analysis of Linear Time Invariant Systems, Filter Design Techniques, Discrete Fourier Transforms (DFT), Fast Algorithms for implementing the DFT including Radix 2, Radix 4 and Mixed Radix Algorithms, Quantization Effects in Discrete Systems and Fourier Analysis of Signals. (Prerequisites: EEEE-602, EEEE-707 and EEEE-709)
Class 3, Lab 0, Credit 3 (F, S)

EEEE-685 Principles of Robotics
An introduction to a wide range of robotics-related topics, including but not limited to sensors, interface design, robot devices applications, mobile robots, intelligent navigation, task planning, coordinate systems and positioning image processing, digital signal processing applications on robots, and controller circuitry design. Pre- requisite for the class is a basic understanding of signals and systems, matrix theory, and computer programming. Software assignments will be given to the students in robotic applications. Students will prepare a project, in which they will complete software or hardware design of an industrial or mobile robot. There will be a two-hour lab additional to the lectures. Students are required to write an IEEE conference paper on their projects. (Graduate Standing) Class 3, Lab 2, Credit 3 (F)

EEEE-689 Fundamentals of MEMs
Microelectromechanical systems (MEMS) are widely used in aerospace, automotive, biotechnology, instrumentation, robotics, manufacturing, and other applications. There is a critical need to synthesize and design high performance MEMS which satisfy the requirements and specifications imposed. Integrated approaches must be applied to design and optimized MEMS, which integrate microelectromechanical motion devices, ICs, and microsensors. This course covers synthesis, design, modeling, simulation, analysis, control and fabrication of MEMS. Synthesis, design and analysis of MEMS will be covered including CAD. (Graduate Standing) Class 3, Lab 0, Credit 3 (F)

EEEE-692 Communication Networks
This course covers communication networks in general and the internet in particular. Topics include layers service models, circuit and packet switching, queuing, pipelining, routing, packet loss and more. A five-layer model is assumed and the top four levels are covered in a top-down approach: starting with the application layer, going down through the transport layer to the network layer and finally the data link layer. Emphasis is placed on wireless networks and network security. Students would perform a basic research assignment consisting of a literature survey, performance analysis and dissemination of results in written and oral presentation. (EEEE-353, MATH-251) Class 3, Lab 0, Credit 3 (S)

EEEE-693 Digital Data Communications
Principles and practices of modern digital data communication systems. Topics include pulse code transmission and error probabilities, M-ary signaling and performance, AWGN channels, band-limited and distorting channels, filter design, equalizers, optimal detection for channels with memory, synchonization methods, non-linear modulation, and introduction to multipath fading channels, spread spectrum and OFDM. Students would perform a basic research assignment consisting of a literature survey, performance analysis and dissemination of results in written and oral presentation. (EEEE-484, EEEE-602) Class 3, Credit 3 (F)

EEEE-694 Sensor Array Processing for Wireless Communications
This course offers a broad overview of sensor-array processing, with a focus on wireless communications. It aims at providing g the students with essential and advanced theoretical and technical knowledge that finds direct application in modern wireless communication systems that employ multi-sensor arrays and/or apply user-multiplexing in the code domain (CDMA). Theory and practices covered in this course can be extended in fields such as radar, sonar, hyperspectral image processing, and biomedical signal processing. Topics covered: uniform linear antenna arrays (inter-element spacing and Nyquist sampling in space); linear beamforming, array beam patterns, array gain, and spatial diversity; interference suppression in the absence of noise (null-steering beamforming); optimal beamforming in AWGN (matched filter); optimal beamforming in the presence of colored interference; estimation of filters from finite measurements and adaptive beamforming (SMI and variants, RLS, LMS and variants, CMA, and AV); BPSK demodulation with antenna arrays (multiple users and AWGN); BPSK demodulation in CDMA (multiple users and AWGN); ML and subspace methods (MUSIC, root MUSIC, Minimum-norm, Linear Predictor, Pisarenko) for Direction-of-arrival estimation; BPSK demodulation with antenna arrays in CDMA systems (space-time processing).(S)

EEEE-707 Engineering Analysis
This course trains students to utilize mathematical techniques from an engineering perspective, and provides essential background for success in graduate level studies. An intensive review of linear and nonlinear ordinary differential equations and Laplace transforms is provided. Laplace transform methods are extended to boundary-value problems and applications to control theory are discussed. Problem solving efficiency is stressed, and to this end, the utility of various available techniques are contrasted. The frequency response of ordinary differential equations is discussed extensively. Applications of linear algebra are examined, including the use of eigenvalue analysis in the solution of linear systems and in multivariate optimization. An introduction to Fourier analysis is also provided. Class 3, Credit 3 (F, S)

EEEE-709 Advanced Engineering Mathematics
Advanced Engineering Mathematics provides the foundations for complex functions, vector calculus and advanced linear algebra and its applications in analyzing and solving a variety of electrical engineering

problems especially in the areas of control, circuit analysis, communication, and signal/image processing. Topics include: complex functions, complex integration, special matrices, vector spaces and subspaces, the nullspace, projection and subspaces, matrix factorization, eigenvalues and eigenvectors, matrix diagonalization, singular value decomposition (SVD), functions of matrices, matrix polynomials and Cayley-Hamilton theorem, state-space modeling, optimization techniques, least squares technique, total least squares, and numerical techniques. Electrical engineering applications will be discussed throughout the course. Class 3, Credit 3 (F, S)

EEEE-710 Advanced Electromagnetic Theory
The primary objective is to provide the mathematical and physical fundamentals necessary for a systematic analysis of electromagnetic field problems. Topics included: electromagnetic theorems and principles, scattering and radiation integrals, TE and TM in rectangular and circular waveguides, hybrid LSE and LSM modes in partially filled guides, dielectric waveguides, the Green's function. The course will also include projects using advanced EM modeling software tools. (EEEE-617, EEEE-629) Class 3, Credit 3 (S)

EEEE-711 Advanced Carrier Injection Devices
A graduate course in the fundamental principles and operating characteristics of carrier-injection-based semiconductor devices. Advanced treatments of pn junction diodes, metal-semiconductor contacts, and bipolar junction transistors form the basis for subsequent examination of more complex carrier-injection devices, including tunnel devices, transferred-electron devices, thyristors and power devices, light-emitting diodes (LEDs), and photodetectors. Topics include heterojunction physics and heterojunction bipolar transistors (HBT). (Graduate Standing) Class 3, Lab 0, Credit 3 (S)

EEEE-712 Advanced Field Effect Devices
An advanced-level course on MOSFETs and submicron MOS devices. Topics include MOS capacitors, gated diodes, long-channel MOSFETs, subthreshold conduction and off-state leakage, short-channel effects, hot-carrier effects, MOS scaling and advanced MOS technologies. (EEEE621) Class 3, Lab 0, Credit 3 (S)

EEEE-713 Solid State Physics
An advanced-level course on solid-state physics, with particular emphasis on the electronic properties of semiconductor materials. Topics include crystal structure, wave propagation in crystalline solids, lattice vibrations, elements of quantum mechanics, elements of statistical mechanics, free-electron theory of metals, Boltzmann transport equation, quantum-mechanical theory of carriers in crystals, energy band theory, equilibrium carrier statistics, excess carriers in semiconductors, carrier transport. (Graduate Standing) Class 3, Lab 0, Credit 3 (F)

EEEE-718 Design & Characterization of Microwave Systems
There are two primary course objectives. Design of experiments to characterize or measure specific quantities, working with the constraints of measurable quantities using the vector network analyzer, and in conjunction with the development of closed form analytical expressions. Design, construction and characterization of microstrip circuitry and antennas for specified design criteria obtaining analytical models, using software tools and developing measurements techniques. Microwave measurement will involve the use of network analyzers, and spectrum analyzers in conjunction with the probe station. Simulated results will be obtained using some popular commercial EM software for the design of microwave circuits and antennas. (EEEE-617, EEEE-629) Class 2, Lab 3, Credit 3 (F)

EEEE-720 Advanced Topics in Digital Systems Design
In this course the student is introduced to a multitude of advanced topics in digital systems design. It is expected that the student is already familiar with the design of synchronous digital systems. The lecture introduces the operation and design principles of asynchronous digital systems, synchronous and asynchronous, pipelined and wave pipelined digital systems. Alternative digital processing paradigms are then presented: data flow, systolic arrays, networks-on-chip, cellular automata, neural networks, and fuzzy logic. Finally, digital computer arithmetic algorithms and their hardware implementation are covered. The projects reinforce the lectures material by offering a hands-on development and system level simulation experience. (EEEE620) Class 3, Credit 3 (S)

EEEE-721 Advanced Topics in Computer System Design
In this course the student is introduced to advanced topics in computer systems design. It is expected that the student is already familiar with the design of a non-pipelined, single core processor. The lectures cover instruction level parallelism, limits of the former, thread level parallelism, multicore processors, optimized hierarchical memory design, storage systems, and large-scale multiprocessors for scientific applications. The projects reinforce the lectures material, by offering a hands-on development and system level simulation experience. (EEEE-621) Class 3, Lab 0, Credit 3 (S)

EEEE-726 Mixed –Signal IC Design
This is the first course in the graduate course sequence in analog integrated circuit design EEEE-726 and EEEE-730. This course covers the following topics: (1)Fundamentals of data conversion (2) Nyquist rate digital-to-analog converters (3) Quantization noise and analysis (4) Nyquist rate analog-to-digital converters (5) Sample and hold circuits (6) Voltage references (7) Static and dynamic testing of digital-to-analog converters (8) Cell based design strategies for integrated circuits (9)Advanced topics in data conversion. (Graduate Standing) Class 3, Lab 0, Credit 3 (S)

EEEE-730 Advanced Analog IC Design
This is the second course in the graduate course sequence in analog integrated circuit design EEEE-726 and EEEE-730. This course covers the following topics: (1) Fundamentals of Filter Design (2) Filter Approximations (3) Frequency and Impedance Scaling (4) Delay Equalization (5) Sensitivity Analysis (6) Sampled Data Theory (7) CMOS Integrated Filters including Switched Capacitor and gm-C Filters (8)Phase Locked Loops (EEEE-726) Class 3, Lab 0, Credit 3 (F)

EEEE-731 Integrated Optical Devices & Systems
This course discusses basic goals, principles and techniques of integrated optical devices and systems, and explains how the various optoelectronic devices of an integrated optical system operate and how they are integrated into a system. Emphasis in this course will be on planar passive optical devices. Topics include optical waveguides, optical couplers, micro-optical resonators, surface plasmons, photonic crystals, modulators, design tools and fabrication techniques, and the applications of optical integrated circuits. Some of the current state-of-the-art devices and systems will be investigated by reference to journal articles. (Graduate Standing) Class 3, Lab 0, Credit 3 (F)

EEEE-733 Robust Control
This course will provide an introduction to the analysis and design of robust feedback control systems. Topics covered: overview of linear algebra and linear systems, H2 and H (spaces, modeling and paradigms for robust control; internal stability; nominal performance (asymptotic tracking); balanced model reduction; uncertainty and robustness; H2 optimal control; H (control; H (loop shaping; controller reduction; and design for robust stability and performance. (EEEE-661) Class 3, Lab 0, Credit 3 (S)

EEEE-765 Optimal Control
The course covers different optimization techniques, as applied to feedback control systems. The main emphasis will be on the design of optimal controllers for digital control systems. The major topics are: Different performance indices, formulation of optimization problem with equality constraints, Lagrange multipliers, Hamiltonian and solution of discrete optimization problem. Discrete Linear Quadratic Regulators (LQR), optimal and suboptimal feedback gains, Riccati equation and its solution, linear quadratic tracking problem. Dynamic Programming - Bellman's principle of optimality - Optimal controllers for discrete and continuous systems - Systems with magnitude constraints on inputs and states. (EEEE-661) Class 3, Lab 0, Credit 3 (S)

EEEE-766 Multivariable Modeling
This course introduces students to the major topics, methods, and issues in modeling multiple-input multiple-output (MIMO) linear systems. The course covers methods of creating models and refining them. Modeling topics include model-order determination, canonical forms, numerical issues in high-order models, creating frequency-response models from time-domain measurements, creating state-space models from frequency-response data, model-order reduction, model transformations and information loss, and

estimating model accuracy of MIMO models. Use of MIMO models in controller design will be discussed. (EEEE-707; Co-requisite: EEEE-661) Class 3, Lab 0, Credit 3 (S)

EEEE-768 Adaptive Signal Processing

An introduction to the fundamental concepts of adaptive systems; open and closed loop adaptive systems; adaptive linear combiner; performance function and minimization; decorrelation of error and input signal. Adaptation algorithms such as steepest descent, LMS and LMS/Newton algorithm. Noise and misadjustments. Applications will include system identification, deconvolution and equalization, adaptive arrays and multipath communication channels. (EEEE-602, EEEE-707, EEEE-709) Class 3, Lab 0, Credit 3 (F, S)

EEEE-771 Optoelectronics

To provide an introduction to the operating principles of optoelectronic devices used in various current and future information processing and transmission systems. Emphasis in this course will be on the active optoelectronic devices used in optical fiber communication systems. Topics include optical resonators, quantum states of light, semiconductor optics, fundamental of lasers, light-emitting diodes, laser diodes, semiconductor photon detectors, optical modulators, quantum wells, and optical fiber communication systems. (Graduate Standing) Class 3, Lab 0, Credits 3 (S)

EEEE-779 Digital Image Processing

This is an introductory course in digital image processing. The course begins with a study of two dimensional (2D) signal processing and transform methods with applications to images. Image sampling is discussed extensively followed by gray level description of images and methods of contrast manipulation including linear/nonlinear transformations, histogram equalization and specification. Image smoothing techniques are considered including spatial and frequency domain low pass filtering, AD-HOC methods of noise removal and median filtering. Following this, methods of image sharpening are studied including derivatives and high pass filtering. Edge and line detection algorithms are discussed using masks and Hough transforms. Finally, methods of image segmentation, restoration, compression and reconstruction are also discussed. Several extensive computer lab assignments are required. (EEEE-678) Class 3, Lab 0, Credit 3 (F)

EEEE-780 Digital Video Processing

In this graduate level course the following topics will be covered: Representation of digital video - introduction and fundamentals; Time-varying image formation models including motion models and geometric image formation; Spatio-temporal sampling including sampling of analog and digital video; two dimensional rectangular and periodic Sampling; sampling of 3-D structures, and reconstruction from samples; Sampling structure conversion including sampling rate change and sampling lattice conversion; Two-dimensional motion estimation including optical flow based methods, block-based methods, Pel-recursive methods, Bayesian methods based on Gibbs Random Fields; Three-dimensional motion estimation and segmentation including methods using point correspondences, optical flow & direct methods, motion segmentation, and stereo and motion tracking. (EEEE-779) Class 3, Lab 0, Credit 3 (S)

EEEE-781 Image and Video Compression

This course studies the fundamental technologies used in image and video compression techniques and international standards such as JPEG and MPEG. At the highest level, all visual data compression techniques can be reduced to three fundamental building blocks: transformation or decomposition (examples are discrete cosine transform or DCT, wavelets, differential pulse code modulation or DPCM and motion compensation), quantization (strategies include scalar vs. vector quantization, uniform vs. nonuniform, Lloyd-Max and entropy-constrained quantization) and symbol modeling and encoding (the concept of Markov source and its entropy, context modeling, variable length coding techniques such as Huffman and arithmetic coding and Golomb-Rice coding). This course studies all of these fundamental concepts in great detail in addition to their practical applications in leading image and video coding standards. The study cases include a comprehensive review of the JPEG lossless compression standard (based on pixel prediction and Huffman coding), the JPEG lossy compression standard (based on DCT and Huffman coding), a detailed study of wavelet decomposition and a brief overview of the MPEG family of standards (employing motion compensation in addition to aforementioned techniques). (EEEE-779) Class 3, Credit 3 (S)

EEEE-784 Advanced Robotics
This course explores advance topics in mobile robots and manipulators. Mobile robot navigation, path planning, room mapping, autonomous navigation are the main mobile robot topics. In addition, dynamic analysis of manipulators, forces and trajectory planning of manipulators, and novel methods for inverse kinematics and control of manipulators will also be explored. The pre-requisite for this course is Principles of Robotics. However, students would have better understanding of the topics if they had Control Systems and Mechatronics courses as well. The course will be a project based course requiring exploration of a novel area in Robotics and writing an IEEE conference level paper. (EEEE-685) Class 3, Lab 0, Credit 3 (S)

EEEE-787 MEMS Evaluation
This course focuses on evaluation of MEMS, microsystems and microelectromechanical motion devices utilizing MEMS testing and characterization. Evaluations are performed using performance evaluation matrices, comprehensive performance analysis and functionality. Applications of advanced software and hardware in MEMS evaluation will be covered. (Graduate standing) Class 3, Credit 3 (S)

EEEE-789 Special Topics
Topics and subject areas that are not regularly offered are provided under this course. Such courses are offered in a normal format; that is, regularly scheduled class sessions with an instructor. (Graduate Standing) Class 3, Credit 3 (F, S,)

EEEE-790 Thesis
An independent engineering project or research problem to demonstrate professional maturity. A formal written thesis and an oral defense are required. The student must obtain the approval of an appropriate faculty member to guide the thesis before registering for the thesis. A thesis may be used to earn a maximum of 6 credits. (Graduate Standing and department approval required) Class 0; Credit 1-6 (F, S, Su)

EEEE-792 Graduate Paper
This course is used to fulfill the graduate paper requirement under the non-thesis option for the MS degree in electrical engineering. The student must obtain the approval of an appropriate faculty member to supervise the paper before registering for this course. (Department approval required) Class 0, Credit 3 (F, S, SU)

EEEE-793 Error Detection & Error Correction
This course covers linear algebraic block codes, convolutional codes, turbo codes, and low-density parity-check codes. The fundamental structure of linear block code will be developed and applied to performance calculations. The structure of cyclic codes will be developed and applied to encoders and decoders. The major error correction methods, including error trapping, majority logic decoding and the BCH encoder and decoder algorithms will be developed. The Viterbi and sequential decoding algorithms will be studied. Questions of system performance, speed and complexity will be examined. Class 3, Credit 3 (F)

EEEE-794 Information Theory
This course introduces the student to the fundamental concepts and results of information theory. This is a very important course for students who want to specialize in signal processing, image processing, or digital communication. Topics include definition of information, mutual information, average information or entropy, entropy as a measure of average uncertainty, information sources and source coding, Huffman codes, run-length constraints, discrete memoryless channels, channel coding theorem, channel capacity and Shannon's theorem, noisy channels, continuous sources and channels, coding in the presence of noise, performance bounds for data transmission, rate distortion theory. (EEEE-602) Class 3, Lab 0, Credit 3 (S)

EEEE-795 Graduate Seminar
The objective of this course is to introduce full time Electrical Engineering BS/MS and incoming graduate students to the graduate programs, campus resources to support research. Presentations from faculty, upper

division MS/PhD students, staff, and off campus speakers will provide a basis for student selection of research topics, comprehensive literature review, and modeling effective conduct and presentation of research. All first year graduate students enrolled full time are required to successfully complete two semesters of this seminar. Class 1, Credit 0 (F, S)

EEEE-797 Wireless Communication

The course will cover advanced topics in wireless communications for voice, data and multimedia. Topics covered are: 1) Channel modeling: Overview of current wireless systems, modeling wireless channels, path loss for different environments, log-normal shadowing, flat and frequency-selective multipath fading, LS estimation of channel parameters, and capacity limits of wireless communication channels. 2) Transmission over fading channels, 3) Techniques to improve the speed and performance of wireless inks (adaptive modulation and diversity techniques such as maximum gain combining to compensate for flat-fading). 4) Techniques to combat frequency-selective fading (adaptive equalization, space time coding, multicarrier modulation (OFDM), and spread spectrum). 5) Applications for these systems, including the evolution of cell phones and PDAs, sensor networks will be discussed. (EEEE-602, EEEE-693) Class 3, Lab 0, Credit 3 (S)

EEEE-799 Independent Study

This course is used by students who plan to study a topic on an independent study basis. The student must obtain the permission of the appropriate faculty member before registering for the course. Class 0, Credit 1-3 (F, S, SU)

Appendix E: Microelectronic Engineering (MCEE) Course Descriptions

600 & 800 Level Courses in Microelectronic Engineering (all courses earn 3 credits unless otherwise noted)

MCEE-601 Microelectronic Fabrication
This course introduces the beginning graduate student to the fabrication of solid-state devices and integrated circuits. The course presents an introduction to basic electronic components and devices, lay outs, unit processes common to all IC technologies such as substrate preparation, oxidation, diffusion and ion implantation. The course will focus on basic silicon processing. The students will be introduced to process modeling using a simulation tool such as SUPREM. There is a lab for the on campus section (01), and a discussion of laboratory results and a graduate paper for the distance learning-section (90). The lab consists of conducting a basic metal gate PMOS process in the RIT clean room facility to fabricate and test a PMOS integrated circuit test ship. Laboratory work also provides an introduction to basic IC fabrication processes and safety. (Graduate standing or permission of the instructor) Class 3, Lab 3, Credit 3 (F)

MCEE-602 Semiconductor Process Integration
This is an advanced level course in Integrated Circuit Devices and process technology. A detailed study of processing modules in modern semiconductor fabrication sequences will be done through simulation. Device engineering challenges such as shallow-junction formation, fin FETs, ultra-thin gate dielectrics, and replacement metal gates are covered. Particular emphasis will be placed on non-equilibrium effects. Silvaco Athena and Atlas will be used extensively for simulation. Class 3, Lab 2, Credit 3 (S)

MCEE-603 Thin Films
This course focuses on the deposition and etching of thin films of conductive and insulating materials for IC fabrication. A thorough overview of vacuum technology is presented to familiarize the student with the challenges of creating and operating in a controlled environment. Physical and Chemical Vapor Deposition (PVD & CVD) are discussed as methods of film deposition. Plasma etching and Chemical Mechanical Planarization (CMP) are studied as methods for selective removal of materials. Applications of these fundamental thin film processes to IC manufacturing are presented. (MCEE-601 Microelectronic Fabrication) Class 3, Lab 3, Credit 3 (F, S)

MCEE-605 Lithography Materials and Processes
Microlithography Materials and Processes covers the chemical aspects of microlithography and resist processes. Fundamentals of polymer technology will be addressed and the chemistry of various resist platforms including novolac, styrene, and acrylate systems will be covered. Double patterning materials will also be studied. Topics include the principles of photoresist materials, including polymer synthesis, photochemistry, processing technologies and methods of process optimization. Also advanced lithographic techniques and materials, including multi-layer techniques for BARC, double patterning, TARC, and next generation materials and processes are applied to optical lithography. (CHMG-131 Gen Chemistry for Engineers or equivalent) Class 3, Lab 3, Credit 3 (F, S)

MCEE-615 Nanolithography Systems
An advanced course covering the physical aspects of micro- and nano-lithography. Image formation in projection and proximity systems are studied. Makes use of optical concepts as applied to lithographic systems. Fresnel diffraction, Fraunhofer diffraction, and Fourier optics are utilized to understand diffraction-limited imaging processes and optimization. Topics include illumination, lens parameters, image assessment, resolution, phase-shift masking, and resist interactions as well as non-optical systems such as EUV, maskless, e-beam, and nanoimprint. Lithographic systems are designed and optimized through use of modeling and simulation packages. (MCEE-605 Lithographic Materials and Processes) Class 3, Lab 3, Credit 3 (F, S)

MCEE-620 Photovoltaic Science and Engineering
This course focuses on the principle and engineering fundamentals of photovoltaic (PV) energy conversion. The course covers modern silicon PV devices, including the basic physics, ideal and non-ideal models,

device parameters and design, and device fabrication. The course discusses crystalline, multi-crystalline, amorphous thin films solar cells and their manufacturing. Students will become familiar with how basic semiconductor processes and how they are employed in solar cells manufacturing. The course further introduces third generation advanced photovoltaic concepts including compound semiconductors, spectral conversion, and organic and polymeric devices. PV applications, environmental, sustainability and economic issues will also be discussed. Evaluations include assignments and exams, a research/term paper on a current PV topic. (Permission of Instructor) Class 3, Lab 3, Credit 3 (S)

MCEE-699 Graduate Co-op
Up to six months of full-time, paid employment in the microelectronic engineering field. See the graduate program coordinator or RIT's Office of Cooperative Education for further details. (Department approval) Credit 0 (F, S, SU)

MCEE-704 Physical Modeling of Semiconductor Devices
MCEE-704 is a senior or graduate level course on the application of simulation tools for physical design and verification of the operation of semiconductor devices. The goal of the course is to provide a more in-depth understanding of device physics through the use of simulation tools. Technology CAD tools include Silvaco (Athena/Atlas) for device simulation. The lecture will explore the various models that are used for device simulation, emphasizing the importance of complex interactions and 2-D effects as devices are scaled deep-submicron. Laboratory work involves the simulation of various device structures. Investigations will explore how changes in the device structure can influence device operation. (Permission of Instructor) Class 3, Lab 2, Credit 3 (F)

MCEE-706 Compound Semiconductor Devices
This course introduces students to the fundamentals of III-V, SiGe and Silicon on Insulator (SOI) devices and fabrication technologies. The course will first discuss the band structure of the SiGe material system, and how its properties of band structure and enhanced mobility may be utilized to improve traditional Si devices. Basic heterojunciton theory is introduced to students. Some specific applications that are introduced include heterojunction bipolar transistors (HBTs), SiGe-channel MOS devices, high-electron mobility transistors (HEMTs) and tunnel FETS. Fabrication technologies for realizing SOI substrates that include SIMOX and SMART CUT technologies are described. The physics of transistors built on SOI substrates will be discussed. At the completion of the course, students will write a review paper on a topic related to the course. (Permission of instructor) Class 3, Lab 3, Credit 3 (F)

MCEE-713 Quantum and Solid-State Physics for Nanostructures
This course describes the key elements of quantum mechanics and solid state physics that are necessary in understanding the modern semiconductor devices. Quantum mechanical topics include solution of Schrodinger equation solution for potential wells and barriers, subsequently applied to tunneling and carrier confinement. Solid state topics include electronic structure of atoms, crystal structures, direct and reciprocal lattices. Detailed discussion is devoted to energy band theory, effective mass theory, energy-momentum relations in direct and indirect band gap semiconductors, intrinsic and extrinsic semiconductors, statistical physics applied to carriers in semiconductors, scattering and generation and recombination processes. (Graduate Standing) Class 3, Lab 0, Credit 3 (F)

MCEE-730 Metrology for Failure Analysis and Yield of IC's
Successful IC manufacturing must detect defects (the non-idealities) that occur in a process), eliminate those defects that preclude functional devices (yield enhancement), and functionality for up to ten years of use in the field (reliability). Course surveys current CMOS manufacturing to compile a list of critical parameters and steps to monitor during manufacturing. This survey is followed with an in depth look at the theory and instrumentation of the tools utilized to monitor these parameters. Tool set includes optical instrumentation, electron microscopy, surface analysis techniques, and electrical measurements. Case studies from industry and prior students are reviewed. Students are required to perform a project either exploring a technique not covered in class, or to apply their course knowledge to a practical problem. (MCEE-201 IC Technology or Equivalent MCEE-360 Semiconductor Devices or Equivalent Permission of Instructor) Class 3, Lab, Credit 3 (F)

MCEE-732 Microelectronics Manufacturing

This course focuses on CMOS manufacturing. Topics include CMOS process technology, work in progress tracking, CMOS calculations, process technology, long channel and short channel MOSFET, isolation technologies, back-end processing and packaging. Associated is a lab for on-campus section (01) and a graduate paper/case study for distance learning section (90). The laboratory for this course is the student-run factory. Topics include Lot tracking, query processing, data collection, lot history, cycle time, turns, CPK and statistical process control, measuring factory performance, factory modeling and scheduling, cycle time management, cost of ownership, defect reduction and yield enhancement, reliability, process modeling and RIT's advanced CMOS process. Silicon wafers are processed through an entire CMOS process and tested. Students design unit processes and integrate them into a complete process. Students evaluate the process steps with calculations, simulations and lot history, and test completed devices. (MCEE-601) Class 3, Lab 3, Credit 3 (S)

MCEE-770 MEMs Fabrication

This course will provide an opportunity for the student to become familiar with the design, fabrication technology and applications of Microelectromechanical systems. This is one of the fastest growing areas in the semiconductor business. Today's MEMS devices include accelerometers, pressure sensors, flow sensors, chemical sensors, energy harvesting and more. These devices have wide variety of applications including automotive, consumer, military, scientific, and biomedical. Students will select a MEMS device/project to be made and then design, fabricate, test, prepare a project presentation and final paper. (MCEE601, EEEE587/EEEE787) Class 3, Lab 3, Credit 3 (F)

MCEE-777 Master of Engineering Internship

This course number is used to fulfill the internship requirement for the master of engineering degree program. The student must obtain the approval of the department head before registering for this course. (Advisor approval) Class 0, Lab 0, Credit 4 (F, S, S)

MCEE-789 Special Topics

This is a variable credit, variable special topics course that can be in the form of a course that is not offered on a regular basis. (Advisor approval) Class 1-3, Lab 0, Credit 1-3 (F, S, S)

MCEE-790 MS Thesis

The master's thesis in microelectronic engineering requires the student to prepare a written thesis proposal for approval by the faculty; select a thesis topic, adviser and committee; present and defend thesis before a thesis committee; submit a bound copy of the thesis to the library and to the department; prepare a written paper in a short format suitable for submission for publication in a journal; complete course work and thesis within a seven-year period; register for one credit of Continuation of Thesis each school term (except summer) after the 30 credits required for the master's degree until the thesis is completed. (Graduate standing in MS in microelectronic engineering, Advisor approval) Class 1; Credit 1-6 (F, S)

MCEE-795 Microelectronics Research Methods

Weekly seminar series intended to present the state of the art in microelectronics research. Other research-related topics will be presented such as library search techniques, contemporary issues, ethics, patent considerations, small business opportunities, technical writing, technical reviews, effective presentations, etc. Required of all MS microelectronic engineering students for one credit up to a total 3 credits. Class 1, Lab 0, Credit 1 (F, S)

MCEE-799 Graduate Independent Study

This course number should be used by students who plan to study a topic on an independent basis under the guidance of a faculty member. A written proposal with an independent study form is to be submitted to the sponsoring faculty member and approved by the department head prior to the commencement of work. (Advisor approval) Credit 1-3 (F, S, S)

Appendix F: Sample MSEE Thesis Title Page

THE PURPLE PLAGUE

by

Chef Boyardee

A Thesis Submitted

in

Partial Fulfillment

of the

Requirements for the Degree of

MASTER OF SCIENCE

in

Electrical Engineering

Approved by:

PROF. ______________________________

(Thesis Advisor's Name, Printed)

PROF. ______________________________

PROF. ______________________________

PROF. ______________________________

(Department Head's Name, Printed)

DEPARTMENT OF ELECTRICAL AND MICROELECTRONIC ENGINEERING

KATE GLEASON COLLEGE OF ENGINEERING

ROCHESTER INSTITUTE OF TECHNOLOGY

ROCHESTER, NEW YORK

MAY, 2016

Appendix G: Sample MSEE Graduate Paper Title Page

THE PURPLE PLAGUE

by

Chef Boyardee

A Graduate Paper Submitted

in

Partial Fulfillment

of the

Requirements for the Degree of

MASTER OF SCIENCE

in

Electrical Engineering

Approved by:

PROF. ____

(Graduate Paper Advisor's Name, Printed)

PROF. ____

(Department Head's Name, Printed)

DEPARTMENT OF ELECTRICAL AND MICROELECTRONIC ENGINEERING

KATE GLEASON COLLEGE OF ENGINEERING

ROCHESTER INSTITUTE OF TECHNOLOGY

ROCHESTER, NEW YORK

MAY, 2016

Appendix H: Sample MS MicroE Thesis Title Page

THE PURPLE PLAGUE

by

Chef Boyardee

A Thesis Submitted

in

Partial Fulfillment

of the

Requirements for the Degree of

MASTER OF SCIENCE

in

Microelectronic Engineering

Approved by:

PROF. ______________________________

(Thesis Advisor's Name, Printed)

PROF. ______________________________

PROF. ______________________________

PROF.

(Program Director's Name, Printed

PROF. ______________________________

(Department Head's Name, Printed)

DEPARTMENT OF ELECTRICAL AND MICROELECTRONIC ENGINEERING

KATE GLEASON COLLEGE OF ENGINEERING

ROCHESTER INSTITUTE OF TECHNOLOGY

ROCHESTER, NEW YORK

MAY, 2016

Appendix J: Sample Table of Contents for Graduate Paper and Thesis

TABLE OF CONTENTS

Appendix K: EME Faculty Research (2013-2015): Abstracts

Funding Agencies:

1. National Science Foundation
2. National Institutes of Health
3. Department of Defense, Office of Naval Research
4. NYS.NYSERDA
5. Google
6. National Semiconductor
7. General Motors
8. nBn Technologie
9. CSpeed, Syracuse NY
10. Tokyo Electron, Austin, T
11. Protequus LLC
12. MKS ENI Products
13. Amazon web services (AWS)
14. Corning Incorporated
15. NYSTAR Center for Emerging & Innovative Sciences (CEIS)
16. Hewlett-Packard Corporation
17. NSF Silicon Solar Consortium

I. Bio-Medical: David Borkholder

Funded by:
National Science Foundation
National Institutes of Health
Google
National Semiconductor

Journal Publications

1. Jeffrey S. Lillie, Alexander S. Liberson, David A. Borkholder, "Quantification of Hemodynamic Pulse Wave Velocity Based on a Thick Wall Multi-Layer Model for Blood Vessels," Journal of Fluid Flow, Heat and Mass Transfer, Accepted March 2016.

   Pulse wave velocity (PWV) is an important index of arterial hemodynamics, which lays the foundation for continuous, noninvasive blood pressure automated monitoring. The goal of this paper is to examine the accuracy of PWV prediction based on a traditional homogeneous structural model for thin-walled arterial segments. In reality arteries are described as composite heterogeneous hyperelastic structures, where the thickness dimension cannot be considered small compared to the cross section size. In this paper we present a hemodynamic fluid - structure interaction model accounting for the variation of geometry and material properties in a radial direction. The model is suitable to account for the highly nonlinear orthotropic material undergoing finite deformation for each layer. Numerical analysis of single and two layer arterial segments shows that a single thick layer model provides sufficient accuracy to predict PWV. The dependence of PWV on pressure for five vessels of different thicknesses is compared against a traditional thin wall model of a membrane shell interacting with an incompressible fluid. The presented thick wall model provides greater accuracy in the prediction of PWV, and will be important for blood pressure estimation based on PWV measurements.

2. Jing Ouyang, Denis Cormier, Scott A. Williams, and David A. Borkholder, "Photonic Sintering of Aerosol Jet Printed Lead Zirconate Titanate (PZT) Thick Films," J. Am. Ceram. Soc., 1–9 (2016) DOI: 10.1111.

   Lead Zirconate Titanate (PZT) is a commonly used piezoelec- tric material due to its high piezoelectric response. We demon- strate a new method of printing and sintering micro-scale PZT films with low substrate temperature increase. Self-prepared PZT ink was Aerosol-Jet printed on stainless steel substrates. After drying for 2 h in vacuum at 200°C, the printed PZT films were divided into two groups. The first group was traditionally sintered, using a thermal process at 1000°C for 1 h in an Argon environment. The second group was photonically sintered using repetitive sub-msec pulses of high intensity broad spectrum light in an atmospheric environment. The highest measured substrate temperature during photonic sintering was 170.7°C, enabling processing on low melting point substrates. Ferroelectric measurements were performed with a low-fre- quency sinusoidal signal. The remanent polarization (Pr) and coercive field (Ec) for thermally sintered PZT film were 17.1 μC/cm2 and 6.3 kV/cm, respectively. The photonically sintered film had 32.4 μC/cm2 Pr and 6.7 kV/cm Ec. After poling the samples with 20 kV/cm electric field for 2 h at 150°C, the piezoelectric voltage constant (g33) was measured for the two film groups yielding – 16.9 x 10– 3 (V m) N (thermally sintered) and – 17.9 x 10– 3 (V m) N (photonically sintered). Both factors indicate the PZT films were successfully sintered using both methods, with the photonically sintered material exhibiting superior electrical properties. To further validate photonic sintering of PZT on low melting point substrates, the process and measurements were repeated using a polyethylene terephthalate (PET) substrate. The measured Pr and Ec were 23.1 μC/cm2 and 5.1 kV/cm, respectively. The g33 was – 17.3 x 10– 3 (V –1m) Photonic sintering of thick film PZT directly on low melting point substrates eliminates the need for complex layer transfer processes often associated with flexible PZT transducers.

3. Getpreecharsawas J, McGrath J, **Borkholder DA**, The electric field strength in orifice-like nanopores of ultrathin membranes. Nanotechnology, 26(4) (2015): 045704. doi:10.1088/0957-4484/26/4/045704

   Here we show that the electric field inside an ultrathin membrane is weaker than conventional theory would predict, and that the reduced field is predictive of measured electroosmotic flow rates. Our theoretical analysis shows that the electric field inside a charged nanopore is affected by end effects and dependent on the Dukhin number Du when the pore length-to-diameter aspect ratio λ is less than 80 for Du ≪ 1 or 300 for Du ≫ 1. The electric field follows an unconventional scaling law; it no longer scales uniformly with the thickness of membrane, but with the local value of λ for each nanopore.

4. Lillie JS, Liberson AS, Mix D, Schwarz QS, Chandra A, Phillips DB, Day SW, **Borkholder, DA**, Pulse wave velocity prediction and compliance assessment in elastic arterial segments. Cardiovascular Engineering and Technology, 6(1):49-58 (2015):

   Pressure wave velocity (PWV) is commonly used as a clinical marker of vascular elasticity. Recent studies have increased clinical interest in also analyzing the impact of heart rate (HR), blood pressure, and left ventricular ejection time (LVET) on PWV. In this article we focus on the development of a theoretical one-dimensional model and validation via direct measurement of the impact of ejection time and peak pressure on PWV using an in vitro hemodynamic simulator. A simple nonlinear traveling wave model was developed for a compliant thin-walled elastic tube filled with an incompressible fluid. This model accounts for the convective fluid phenomena, elastic vessel deformation, radial motion, and inertia of the wall. An exact analytical solution for PWV is presented which incorporates peak pressure, ejection time, ejection volume, and modulus of elasticity. To assess arterial compliance, the solution is introduced in an alternative form, explicitly determining compliance of the wall as a function of the other variables. The model predicts PWV in good agreement with the measured values with a maximum difference of 3.0%. The results indicate an inverse quadratic relationship (R^2=.99) between ejection time and PWV, with ejection time dominating the PWV shifts (12%) over those observed with changes in peak pressure (2%). Our modeling and validation results both explain and support the emerging evidence that, both in clinical practice and clinical research, cardiac systolic function related variables should be regularly taken into account when interpreting arterial function indices, PWV.

5. Matthew Kelly, Vincent Amuso, David Eddins, and **David A Borkholder**, "The Focal Index as a Singular Metric for Beamforming Effectiveness," Journal of the Acoustical Society of America, 136.5 (2014): 2654-2664.

   Hard of hearing individuals frequently cite intelligibility problems in multi-talker environments. Microphone arrays performing time delay beamforming address conditions of poor signal-to-noise ratio by spatially filtering incoming sound. Existing beampattern metrics including peak side lobe level, integrated side lobe level, beamwidth, and planar directivity index fail to quantitatively capture all elements essential for improving speech intelligibility in multi- talker situations. The focal index (FI) was developed here to address these deficiencies. Simulations were performed to exemplify the robust nature of the FI and to demonstrate the utility of this metric for driving array parameter selection. Beampatterns were generated and the metrics were calculated and evaluated against the strict unidirectional requirements for the array. Array performance was assessed by human subjects in a speech recognition task with competing speech from multiple locations. Simulations of array output were presented under conditions differing in array sparsity. The resulting human subject data was used to demonstrate the linear relationship (R2 > 0.975) between speech-intelligibility-weighted FI (SII-FI) and the signal-to- noise ratio thresholds for 20% and 80% correct responses. Data indicate that the FI and SII-FI are robust singular metrics for determining the effectiveness of the array.

6. Liberson A., Lillie J, **Borkholder DA**, "Numerical Solution for the Boussinesq Type Models with Application to Arterial Flow," Journal of Fluid Flow, 1 (2014).

   A family of classical Boussinesq system of nonlinear wave theory is presented in a form of conservative equations supplemented by Riemann solver, which is a fundamental block in the Godunov frame formulation of flow problems. The governing system simulates different physical phenomena, such as propagation of a small amplitude waves on a surface of water, or pulse wave propagation in compliant thin walled arterial systems. While the first model is for verification purpose only, pulse wave propagation through the junction of thin walled elastic branches is of primary interest. The inertial effects associated with transversal motion of the wall are introduced, affirming the dispersive nature of pulsating waves. The problem of accounting for branching and possible discontinuity of wall properties is addressed. Preliminary analysis is presented which leads to the correct jump conditions across bifurcated area. As a result, the model accurately describes the formation of transmission and reflection waves at bifurcation, including effects of discontinuities. The Riemann solver supplies the inter cell flux and junction fluxes, based on conservation of volume, momentum and energy, with account of losses associated with the flow turn angle at bifurcation. An implicit monotonic total variation diminishing (TVD) scheme, second order accurate in time and space has been applied for the analysis of solitary wave solution in bifurcated arteries. Numerical results are in a good agreement with the known analytical and numerical solutions reported elsewhere. Based on direct computational analysis the inverse solution was obtained, calculating the local elastic properties of the arterial wall, using typical diagnostic measurements. Mathematical modelling presented in this work leads to a physiological understanding and interpretation of diagnostic measurements of the wave forms of a blood pressure, flow rate and an artery wall deflection.

7. Haghpanahi, Masoumeh, and **David A. Borkholder**. "Fetal QRS extraction from abdominal recordings via model-based signal processing and intelligent signal merging." Physiological measurement 35.8 (2014): 1591.

   Noninvasive fetal ECG (fECG) monitoring has potential applications in diagnosing congenital heart diseases in a timely manner and assisting clinicians to make more appropriate decisions during labor. However, despite advances in signal processing and machine learning techniques, the analysis of fECG signals has still remained in its preliminary stages. In this work, we describe an algorithm to automatically locate QRS complexes in noninvasive fECG signals obtained from a set of four electrodes placed on the mother's abdomen. The algorithm is based on an iterative decomposition of the maternal and fetal subspaces and filtering of the maternal ECG (mECG) components from the fECG recordings. Once the maternal components are removed, a novel merging technique is applied to merge the signals and detect the fetal QRS (fQRS) complexes. The algorithm was trained and tested on the fECG datasets provided by the PhysioNet/CinC challenge 2013. The final results indicate that the algorithm is able to detect fetal peaks for a variety of signals with different morphologies and strength levels encountered in clinical practice.

CONFERENCE PUBLICATIONS

8. Ouyang J, Penmetcha AR, Cormier D, Borkholder DA, "Photonically sintered PZT energy harvester," ASME 2015 International Mechanical Engineering Congress & Exposition, Nov 13-19 (2015).

   This paper reports an Aerosol-Jet printed micro scale Lead Zirconate Titanate (PZT) energy harvester directly sintered on a low melting point substrate in less than 1 msec using photonic sintering technology. To improve the output signal, d33 piezoelectric mode was employed by patterning silver electrodes as an interdigitated structure on top of a PZT film. The size of the device is 15.5 mm ×13.5 mm ×0.2 mm. Up to 2.4 V was measured at 145 MPa tensile bending stress level in the device after poling at 180 °C for 2 hours with an electric field of 30 kV/cm. Using an oscillating stress (~2.5 Hz) of approximately 145 MPa, the power as a function of load was determined by connecting the device with various series resistive loads. A maximal power of 0.1 μW was generated when driving into a 10 MΩ load. A PZT energy harvester, for the first time, is demonstrated which has been directly printed and sintered on a low melting temperature flexible substrate without a film transfer processes. This not only dramatically simplifies the fabrication process, but expands the possible substrate materials for PZT energy harvesters.

9. **D.A. Borkholder,** "Concept to Commercialization of a MEMS-Based Blast Dosimetry System." In Solid-State Sensors, Actuators and Microsystems Conference (TRANSDUCERS), 2015 18th International, pp. 281-286. IEEE, 2015. (Invited Talk).

   Traumatic brain injury (TBI) has emerged as the signature injury of modern war, impacting over 300,000 Servicemembers since 2000. While 82% of these injuries are classified mild, there is significant concern with the potential for long-lasting neurocognitive and neuro- degenerative effects. Diagnosis of mild TBI is difficult, with symptoms that are wide-ranging, non-specific, and often delayed in onset. The Blast Gauge® System was created to provide an objective measure of blast overpressure and acceleration exposure, providing triage data to assist in identifying soldiers at risk of TBI and detailed waveforms to enable correlation of singular and repetitive exposure to acute and chronic injury. From concept to deployment in 11 months and company formation to first product shipment in 4 months, this MEMS-based soldier-borne blast dosimeter has rapidly provided a new capability to track exposure in training and operations for the US DoD, law enforcement, and international militaries. Widespread deployment of the technology has yielded new insight into previously unrecognized dangers of heavy weapons training and captured valuable information about IED exposures in theater.

10. Jeffrey S. Lillie, Alexander S. Liberson, **David A. Borkholder**, "Pulse Wave Velocity Prediction in Multi-Layer Thick Wall Arterial Segments," Proceedings of the 2nd International Conference on Fluid Flow, Heat and Mass Transfer Ottawa, Ontario, Canada, April 30 – May 1, 2015 Paper No. 163

    Pulse wave velocity (PWV) is an important index of arterial hemodynamics, which lays the foundation for continuous, noninvasive blood pressure automated monitoring. The goal of this paper is to re-examine the accuracy of PWV prediction based on a traditional homogeneous structural model for thin-walled arterial segments. In reality arteries are described as composite heterogeneous hyperelastic structures, where the thickness dimension cannot be considered small compared to the cross section size. In this paper we present a hemodynamic fluid - structure interaction model accounting for the 3D material description of multilayer arterial segments based on its histological information. The model is suitable to account for the highly nonlinear orthotropic material undergoing finite deformation for each layer. An essential ingredient is the notable dependence of results on nonlinear aspects of the model: convective fluid phenomena, hyperelastic constitutive relation for each layer, and finite deformation. The dependence of PWV on pressure for three vessels of different thicknesses is compared against a simplified thin wall model of a membrane shell interacting with an incompressible fluid. Results show an asymptotic accuracy of an order of h/r0 is predicted. This work help lays the foundation for continuous, noninvasive blood pressure automated monitoring based on PWV.

11. Haghpanahi M, Sameni R and **Borkholder D A**. "Scoring consensus of multiple ECG annotators by optimal sequence alignment," 36th Ann. Int. Conf. of the IEEE Engineering in Medicine and Biology Society EMBC'14 (Chicago, Aug. 2014).

    Development of ECG delineation algorithms has been an area of intense research in the field of computational cardiology for the past few decades. However, devising evaluation techniques for scoring and/or merging the results of such algorithms, both in the presence or absence of gold standards, still remains as a challenge. This is mainly due to existence of missed or erroneous determination of fiducial points in the results of different annotation algorithms. The discrepancy between different annotators increases when the reference signal includes arrhythmias or significant noise and its morphology deviates from a clean ECG signal. In this work, we propose a new approach to evaluate and compare the results of different annotators under such conditions. Specifically, we use sequence alignment techniques similar to those used in bioinformatics for the alignment of gene sequences. Our approach is based on dynamic programming where adequate mismatch penalties, depending on the type of the fiducial point and the underlying signal, are defined to optimally align the annotation sequences. We also discuss how to extend the algorithm for more than two sequences by using suitable data structures to align multiple annotation sequences with each other. Once the sequences are aligned, different heuristics are devised to evaluate the performance against a gold standard annotation, or to merge the results of multiple annotations when no gold standard exists.

ISSUED PATENTS

1. Borkholder DA, Kenyon M, Ramplin R, Sherman K, Wellman M, and Harrison M, "Device for Detecting an Impact Event," US D743,822, issued November 24, 2015.
2. Borkholder DA, DeBusschere BD, "Method for Monitoring Exposure to an Event and Device Thereof." US 9,138,172 B2, issued September 22, 2015.
3. Borkholder DA, Kovacs GTA, Rogers J, "Event Dosimeter Device and Methods Thereof," AU 2012222110, Issued August 6, 2015
4. Borkholder DA, Fassler W, Blair A, Sherman K, DeBusschere D, "Event Monitoring Dosimetry Apparatuses and Methods Thereof," AU 2012222107, Issued June 11, 2015

II. a. Communications: Gill Tsouri

Funded by:
General Motors
nBn Technologies
Google
Cyber Security Research Center (Israel)

1. G. G. R. Tsouri, S. Zambito and J. Venkataraman, "On the Benefits of Creeping Wave Antennas in Reducing Interference between Neighboring Wireless Body Area Networks", accepted for publication in IEEE Transactions on Biomedical Circuits and Systems, 2016.

   We consider the on-body, off-body, and body-to-body channels in wireless body area networks utilizing creeping wave antennas. Experimental setups are used to gather measurements in the 2.4 GHz band with body area networks operating in an office environment. Data packets providing received signal strength indicators are used to assess the performance of the creeping wave antenna in reducing interference at a neighboring on-body access point while supporting reliable on-body communications. Results demonstrate that creeping wave antennas provide reliable on-body communications while significantly reducing inter-network interference; the inter-network interference is shown to be 10dB weaker than the on-body signal. In addition, the inter-network interference when both networks utilize creeping wave antennas is shown to be 3dB weaker than the interference when monopole antennas are used.

2. **G. R. Tsouri** and Z. Li, "On the Benefits of Alternative Color Spaces for Noncontact Heart Rate Measurements using RGB Video Cameras", <u>SPIE Journal of Biomedical Optics, Apr. 2015. (IF: 2.88)</u>

   Existing Video PlethysmoGraphy methods use standard RGB video recordings of the facial region to estimate heart pulse rate without making contact with the person being monitored. Methods achieving high estimation accuracy require considerable signal processing power and result in significant processing latency. High processing power and latency are limiting factors when real-time pulse rate estimation is required or when the sensing platform has no access to high processing power. In this work, we investigate the use of alternative color spaces derived from standard RGB video recordings as a fast light-weight alternative to pulse rate estimation. We consider seven color spaces and compare their performance with state-of-the-art algorithms that use independent component analysis. The comparison is performed over a dataset of 41 video recordings from subjects of varying skin tone and age. Results indicate that the Hue channel provides better estimation accuracy using extremely low computation power and with practically no latency.

3. R. Dautov and **G. R. Tsouri,** "Securing while Sampling in Wireless Body Area Networks with Application to Electrocardiography", *IEEE Journal of Biomedical and Health Informatics*, Jan 2016 **(IF: 1.68)**

   Stringent resource constraints and broadcast transmission in wireless body area network raise serious security concerns when employed in biomedical applications. Protecting data transmission where any minor alteration is potentially harmful is of significant importance in healthcare. Traditional security methods based on public or private key infrastructure require considerable memory and computational resources and present an implementation obstacle in compact sensornodes. This paper proposes a lightweight encryption framework augmenting Compressed Sensing with Wireless Physical Layer Security. Augmenting compressed sensing to secure information is based on the use of the measurement matrix as an encryption key and allows for incorporating security in addition to compression at the time of sampling an analog signal. The proposed approach eliminates the need for a separate encryption algorithm as well as the pre-deployment of a key thereby conserving sensor-node's limited resources. The proposed framework is evaluated using analysis, simulation and experimentation applied to a wireless electrocardiogram setup consisting of a sensor node, an access point, and an eavesdropper performing a proximity attack. Results show that legitimate communication is reliable and secure given that the eavesdropper is located at a reasonable distance from the sensor node and the access point.

3. A. S. Decker, G. C. Cipriano, G. R. Tsouri and J. Lavigne, "Monitoring Pharmacy Student Adherence to World Health Organization Hand Hygiene Indications Using Radio Frequency Identification", accepted for publication in American jour of pharmaceutical education, 2015.

   To improve adherence to hand hygiene indications in the months after instruction using Radio Frequency identification (RFID) enabled hand hygiene stations and twice weekly performance report cards to students.After successful completion of training in World Health Organization (WHO) hand hygiene methods and indications for hand rubbing with alcohol-based products, students volunteered wear radio frequency identification (RFID) name tags everyday in the classroom over a two week period and to follow hand hygiene indications as though the classroom were a new patient care zone. To reinforce hand hygiene practice, we emailed reports to students in the middle at the end of the study period illustrating individual performance. Adherence to the WHO hand hygiene indication for entering and leaving a patient zone was assessed using the classroom as a proxy for a patient zone several months after instruction. Adherence was recorded electronically using the automated RFID enabled hand hygiene station and name tags. Use was benchmarked against class start and end times for first year pharmacy students who use the same classroom everyday for every class. Student satisfaction with the system was assessed by self-administered survey at the end of the study period. The RFID-enabled hand hygiene system and benchmarking reports with performance incentives was feasible, reliable and affordable. Improvements might include a camera for monitoring of the WHO 8-step technique.

4. **G. R. Tsouri** and O. Maimon, "Estimating Respiration Rate from Channel State Information in Wireless Body Area Networks", *IET Electronics Letters*, May 2014. **(IF: 1.04)**

   Respiration rate is an important measure for assessing a patient's health and is typically measured using obtrusive devices. A non-obtrusive method of estimating respiration rate by taking advantage of data packets being sent from sensor nodes in a wireless body area network is proposed and investigated. In contradistinction to other methods, the proposed method does not require dedicated hardware and does not impose overheads on transmission power and throughput. Instead, it makes use of data packets already being sent to support some other physiological monitoring applications such as cardiac, temperature or motion monitoring. The method is demonstrated on a single subject and results are presented from a study including 40 measurements taken from eight subjects. The mean estimation error in the study was 0.58 breaths per minute. The proposed method can be used to augment wireless body monitoring applications with important respiration rate measurements without imposing overheads on the compact sensor nodes.

5. **G. R. Tsouri** and M. Ostertag, "Patient-Specific 12-Lead ECG Reconstruction from Sparse Electrodes using Independent Component Analysis", *IEEE Journal of Biomedical and Health Informatics – Special Issue on Emerging Wireless Body Area Networks for Ubiquitous Healthcare*, Mar. 2014. **(IF: 1.68)**

   We propose and evaluate a method of 12-lead electrocardiogram (ECG) reconstruction from a three-lead set. The method makes use of independent component analysis and results in adaptive patient-specific transforms. The required calibration process is short and makes use of a single beat. We apply the method to two sets of leads: leads I, II, V2 and the Frank XYZ leads. Performance is evaluated via percent correlation calculations between reconstructed and original leads from a publicly available database of 549 ECG recordings. Results depict percent correlation exceeding 96% for almost all leads. Adaptability of the method's transform is shown to compensate for changes in signal propagation conditions due to breathing, resulting in reduced variance of reconstruction accuracy across beats. This implies that the method is robust to changes that occur after the time of calibration. Accurate and adaptive reconstruction has the potential to augment the clinical significance of wireless ECG systems since the number of sensor nodes placed on the body is limited and the subject could be mobile.

CONFERENCE PUBLICATIONS

1. M. S. Shamim, A. Mhatre, N. Mansoor, A. Ganguly and **G. R. Tsouri**, "Temperature-aware Wireless Network-on-Chip Architecture", *IEEE International Green Computing Conference* (IGCC), Nov. 2014.

   Long-range wireless shortcuts in Network-on-Chip (NoC) architectures are shown to significantly improve energy-efficiency in on-chip data transfer. However, over-utilization of the wireless shortcuts and non-uniform traffic patterns may result in thermal hotpots in the NoC links or switches. In this work we propose a cross-layer approach of optimizing the NoC topology to achieve a balanced traffic distribution and temperature-aware routing (TAR) scheme to avoid thermal hotspots. We demonstrate that the proposed wireless NoC architecture is able to reduce temperature of NoC components and the TAR scheme is able to restrict the temperatures near a target threshold value.

2. C. Torbit, K. Tomsic, J. Venkataraman, **G. R. Tsouri**, M. Laifenfeld and M. Dziatczak, "Investigation of Waveguide Effects in Intra-Vehicular Environments", *IEEE Antennas and Propagation Society International Symposium* (APSURSI), Jul. 2014.

   Supporting intra-vehicular sensing using wireless communication is beneficial for eliminating wires and saving costs. The traditional approach is using transmit and receive antennas radiating into the car's open space. Radiated signals are exposed to strong fading due to shadowing and the dynamic nature of the wireless channel. Preliminary experimental observations of the feasibility of propagating a signal over the surface of the car lead to the motivation of the present work. Simulations using CST microwave studio is used to determine the level of wave propagation through a layer of paint and compared to experimental results. A study has been performed for analyzing the surface wave hypothesis at different frequencies.

PATENTS:

1. M. Laifenfeld, **G. R. Tsouri**, General Motors, "Wireless data security between vehicle components", US patent pending, 2015.

2. M. Laifenfeld, **G. R. Tsouri**, Eviatar Tron, General Motors, "Using a vehicle structure as a medium for communication and power distribution", US 20150039312A1, Feb. 2015.

3. **G. R. Tsouri**, S. Dianat, Rochester Institute of Technology, "Method and System for Contactless Detection of Cardiac Activity", US 20140276118, Sep. 2014.
4. **G. R. Tsouri**, S. Dianat, Rochester Institute of Technology, "Method and System for Contactless Detection of Cardiac Activity", US Patent Pending, Mar. 2014.

   A system and method include contactless detecting and tracking cardiac activity by making use of a feedback control system, such as a Phase Locked Loop (PLL), in real-time or from prerecorded signal stream.

II. b. Communications: Panos Markopoulos

Articles in Journals

1. **P. P. Markopoulos**, N. Tsagkarakis, D. A. Pados, and G. N. Karystinos, “Direction-of-arrival estimation with realified L1-norm subspaces," IEEE Transactions on Signal Processing

   The enormously rewarding theory and practice of subspace-based signal direction-of-arrival estimation has been founded largely on the familiar principles of L2-norm singular-value decomposition (SVD) of the sensor-array data matrix. In this paper, for the first time in the literature, we calculate optimally L1-norm principal components of the realified observed data and search in their subspace for signal presence. Extensive simulation studies illustrate the new theoretical developments and demonstrate that the proposed L1-subspace direction-of-arrival estimation method exhibits (i) significant resistance to data-set contamination by intermittent directional jamming and/or faulty measurements and (ii) similar performance to conventional L2-subspace procedures in the absence of data-set contamination.

2. P. P. Markopoulos, G. N. Karystinos, and D. A. Pados, ``Optimal algorithms for L1-subspace signal processing,” IEEE Trans on Signal Processing, vol. 62, pp.5046-5058, Oct 2014.

   We describe ways to define and calculate L1-norm signal subspaces which are less sensitive to outlying data than L2-calculated subspaces. We start with the computation of the L1 maximum-projection principal component of a data matrix containing N signal samples of dimension D. We show that while the general problem is formally NP-hard in asymptotically large N, D, the case of engineering interest of fixed dimension D and asymptotically large sample size N is not. In particular, for the case where the sample size is less than the fixed dimension ($N < D$), we present in explicit form an optimal algorithm of computational cost 2 N. For the case $N \geq D$, we present an optimal algorithm of complexity O(N^D). We generalize to multiple L1-max-projection components and present an explicit optimal L1 subspace calculation algorithm of complexity O(N^(DK−K+1)) where K is the desired number of L1 principal components (subspace rank). We conclude with illustrations of L1-subspace signal processing in the fields of data dimensionality reduction, direction-of-arrival estimation, and image conditioning/restoration.

Articles in Conference Proceedings

1. Y. Liang, P. P. Markopoulos, and E. Saber, ``Subpixel target detection in hyperspectral images with local matched filtering in SLIC superpixels,” IEEE Workshop on Hyperspectral Image and Signal Processing: Evolutions in Remote Sensing (WHISPERS 2016), Los Angeles, CA, August 2016.

   In subpixel-target detection in hyperspectral images, there is well-documented current interest for identifying preferred background covariance matrix estimates to be used in the formation of matched-filter detectors. The traditional approach suggests global covariance matrix estimates, calculated upon all the image pixels, while several recent works suggest locally formed matched filters within image segments. In this work, we propose for the first time local matched filters from background covariance matrices calculated within SLIC superpixels of the image. Our simulation studies illustrate that the proposed SLIC-based matched-filter (SLIC-MF) detector attains performance superior to that of contemporary alternatives that employ different, globally or locally estimated, background statistics.
2. P. P. Markopoulos, ``Reduced-rank filtering on L1-norm Subspaces,” IEEE Sensor Array and Multichannel Signal Processing Workshop, Rio de Janeiro, Brazil, July 2016.

Recent studies in signal processing have unveiled the remarkable outlier-resistance properties of L1-norm subspaces, calculated by means of L1-norm principal component analysis (L1-PCA). In this work, we present for the first time reduced-rank interference-suppressive filtering on L1-norm subspaces of the received signal vectors. Our simulation studies illustrate that the proposed filtering framework allows for successful suppression of coherent interference while, at the same time, it offers sturdy protection against outliers that appear among the training samples.

3. P. P. Markopoulos, ``A novel algorithm for linear discriminant analysis from short training data," IEEE Intl Conference on Image Processing (ICIP 2016), Phoenix, AZ, Sept 2016.

   Statistically-optimal Linear Discriminant Analysis (LDA) is formulated as a maximization that involves the nominal statistics of the classes to be discriminated. In practice, however, these nominal statistics are unknown and estimated from a collection of labeled training data. Accordingly, the nominal LDA basis is approximated by the solution of the popular practical-LDA problem defined upon these estimates. However, when the available training data are few, the solution to practical LDA is known to lie far from the nominal LDA basis. In this work, we propose a novel algorithm that operates on the estimated class statistics and generates a sequence of bases that converges to the solution of practical LDA. Importantly, our studies illustrate that early elements of the proposed sequence exhibit significantly higher approximation to the nominal LDA basis than the converging point and, thus, offer the means for superior classification performance.

4. Y. Liang, P. P. Markopoulos, and E. Saber, ``Subpixel target detection in hyperspectral images from superpixel background statistics," to appear in *IEEE International Geoscience and Remote Sensing Symposium (IGRASS 2016),* Beijing, China, July 2016.

   In the field of subpixel target detection in hyperspectral images, there is well-documented current interest for identifying preferred background covariance matrix estimates, to be used in the formation of matched-filter detectors. In this work, for the first time, we study the case of local background covariance matrix estimation from SLIC-superpixel coherence regions. Interestingly, our experiments illustrate that the SLIC-based matched-filter detector can attain performance superior to that of contemporary alternatives that employ different, globally or locally estimated, background statistics.

5. P. P. Markopoulos, N. Tsagkarakis, D. A. Pados, and G. N. Karystinos, ``Direction-of-arrival estimation from L1-norm Principal Components," to appear in *IEEE International Symposium on Phased Array Systems and Technology (PHASED ARRAY 2016),* Boston, MA, October 2016.

   We present a signal direction-of-arrival (DoA) estimation method that computes outlier-resistant L1-norm principal components [1] of the collected snapshots to estimate the source signal subspace. In the ideal case where all snapshots are outlier-free, the proposed method performs as well as DoA estimation from conventional L2-norm principal components (MUSIC [2]). When snapshots are corrupted by outliers, L1-norm principal components exhibit sturdy resistance and enable superior DoA estimation performance.

6. P. P. Markopoulos, S. Kundu, and D. A. Pados, ``L1-fusion: Robust linear-time image recovery from few severely corrupted copies," in *Proceedings IEEE International Conference on Image Processing,* Quebec City, Canada, Sept 2015, pp. 1225-1229.

   We address the problem of recovering an unknown image of interest, when only few, severely corrupted copies are available. We employ, for the first time in the literature, corruption-resistant L1-Principal-Components (L1-PCs) of the image data-set at hand. Specifically, the calculated L1- PCs are used for reliability-based patch-by-patch fusion of the corrupted image copies into a single high-quality representation of the original image (L1-fusion). Our experimental studies illustrate that the proposed method offers remarkable recovery results for several common corruption types, even under high corruption rate, small number of copies, and varying corruption type among copies. An additional theoretical contribution of this work is that the L1-PC of a data matrix of non-negative entries (e.g., image data) is for the first time shown to be optimally calculable with complexity linear to the matrix dimensions –as of now, the fastest-known optimal algorithm is of polynomial complexity. In the light of this result, L1-fusion is carried out with linear cost comparable to that of the simple copy-averaging alternative. The linear-low cost of L1-fusion allows for the recovered image to be, optionally, further refined by means of sophisticated single-image restoration techniques.

7. N. Tsagkarakis, P. P. Markopoulos, and D. A. Pados, ``Direction finding by complex L1-principal component analysis," in *Proceedings IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 2015),* Stockholm, Sweden, June 2015, pp. 475-479.
   In the light of recent developments in optimal real L1-norm principal-component analysis (PCA), we provide the first algorithm in the literature to carry out L1-PCA of complex-valued data. Then, we use this algorithm to develop a novel subspace-based direction-of-arrival (DoA) estimation method that is resistant to faulty measurements or jamming. As demonstrated by numerical experiments, the proposed algorithm is as effective as state-of-the-art L2-norm methods in clean-data environments and significantly superior when operating on corrupted data.

8. P. P. Markopoulos, N. Tsagkarakis, D. A. Pados, and G. N. Karystinos, ``Direction finding with L1-norm subspaces," in *Proceedings of SPIE, Compressive Sensing Conference, SPIE Defense, Security, and Sensing (DSS 2014),* Baltimore, MD, May 2014, vol. 9109, pp. 9109J-1-9109J-11. (Student Travel Grant Award)
   Conventional subspace-based signal direction-of-arrival estimation methods rely on the familiar L2-norm-derived principal components (singular vectors) of the observed sensor-array data matrix. In this paper, for the first time in the literature, we find the L1-norm maximum projection components of the observed data and search in their subspace for signal presence. We demonstrate that L1-subspace direction-of-arrival estimation exhibits (i) similar performance to L2 (usual singular-value/eigen-vector decomposition) direction-of-arrival estimation under normal nominal-data system operation and (ii) significant resistance to sporadic/occasional directional jamming and/or faulty measurements.

9. S. Kundu, P. P. Markopoulos, and D. A. Pados, ``Fast computation of the L1-principal component of real-valued data," in *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing),* Florence, Italy, May 2014, pp. 8028-8032.
   Recently, Markopoulos et al. [1], [2] presented an optimal algorithm that computes the L1 maximum-projection principal component of any set of N real-valued data vectors of dimension D with complexity polynomial in N, O(N^D). Still, moderate to high values of the data dimension D and/or data record size N may render the optimal algorithm unsuitable for practical implementation due to its exponential in D complexity. In this paper, we present for the first time in the literature a fast greedy single-bit-flipping conditionally optimal iterative algorithm for the computation of the L1 principal component with complexity O(N^3). Detailed numerical studies are carried out demonstrating the effectiveness of the developed algorithm with applications to the general field of data dimensionality reduction and direction-of-arrival estimation

III. a. Digital Systems: Mehran Mozaffari-Kermani

1. A. Mohsen-nia, **M. Mozaffari Kermani**, S. Sur-kolay, A. Raghunathan, and N. K. Jha, "Energy-efficient long-term continuous personal health monitoring," IEEE Trans. Multi-Scale Computing Systems, Accepted and to be published in 2016.
   Continuous health monitoring using wireless body area networks of implantable and wearable medical devices (IWMDs) is envisioned as a transformative approach to healthcare. Rapid advances in biomedical sensors, low-power electronics, and wireless communications have brought this vision to the verge of reality. However, key challenges still remain to be addressed. The constrained sizes of IWMDs imply that they are designed with very limited processing, storage, and battery capacities. Therefore, there is a very strong need for efficiency in data collection, analysis, storage, and communication. In this paper, we first quantify the energy and storage requirements of a continuous personal health monitoring system that uses eight biomedical sensors: (1) heart rate, (2) blood pressure, (3) oxygen saturation, (4) body temperature, (5) blood glucose, (6) accelerometer, (7) electrocardiogram (ECG), and (8) electroencephalogram (EEG). Our analysis suggests that there exists a significant gap between the energy and storage requirements for long-term continuous monitoring and the capabilities of current devices. To enable energy-efficient continuous health monitoring, we propose schemes for sample aggregation, anomaly-driven transmission, and compressive sensing to reduce the overheads of wirelessly transmitting, storing, and encrypting/authenticating the data. We evaluate these techniques and demonstrate that they result in two to three orders-of-magnitude improvements in energy and storage requirements, and can help realize the potential of long-term continuous health monitoring.

2. **M. Mozaffari Kermani,** R. Azarderakhsh, and A. Aghaie, "Reliable and error detection architectures of Pomaranch for false-alarm-sensitive cryptographic applications," IEEE Trans. Very Large Scale Integr. (VLSI) Syst., vol. 23, no. 12, pp. 2804-2812, Dec. 2015.
   Efficient cryptographic architectures are used extensively in sensitive smart infrastructures. Among these architectures are those based on stream ciphers for protection against eavesdropping, especially when these smart and sensitive applications provide life-saving or vital mechanisms. Nevertheless, natural defects call for protection through design for fault detection and reliability. In this paper, we present implications of fault detection cryptographic architectures (Pomaranch in the hardware profile of European Network of Excellence for Cryptology) for smart infrastructures. In addition, we present low-power architectures for its nine-to-seven uneven substitution box [tower field architectures in GF(33)]. Through error simulations, we assess resiliency against false-alarms which might not be tolerated in sensitive intelligent infrastructures as one of our contributions. We further benchmark the feasibility of the proposed approaches through application-specific integrated circuit realizations. Based on the reliability objectives, the proposed architectures are a step-forward toward reaching the desired objective metrics suitable for intelligent, emerging, and sensitive applications.

3. **M. Mozaffari Kermani**, S. Sur-kolay, A. Raghunathan, and N. K. Jha, "Systematic poisoning attacks on and defenses for machine learning in healthcare," IEEE Trans. Information Technology in Biomedicine, vol. 19, no. 6, pp. 1893-1905, Nov. 2015.
   Machine learning is being used in a wide range of application domains to discover patterns in large datasets. Increasingly, the results of machine learning drive critical decisions

in applications related to healthcare and biomedicine. Such health-related applications are often sensitive, and thus, any security breach would be catastrophic. Naturally, the integrity of the results computed by machine learning is of great importance. Recent research has shown that some machine-learning algorithms can be compromised by augmenting their training datasets with malicious data, leading to a new class of attacks called poisoning attacks. Hindrance of a diagnosis may have life-threatening consequences and could cause distrust. On the other hand, not only may a false diagnosis prompt users to distrust the machine-learning algorithm and even abandon the entire system but also such a false positive classification may cause patient distress. In this paper, we present a systematic, algorithm-independent approach for mounting poisoning attacks across a wide range of machine-learning algorithms and healthcare datasets. The proposed attack procedure generates input data, which, when added to the training set, can either cause the results of machine learning to have targeted errors (e.g., increase the likelihood of classification into a specific class), or simply introduce arbitrary errors (incorrect classification). These attacks may be applied to both fixed and evolving datasets. They can be applied even when only statistics of the training dataset are available or, in some cases, even without access to the training dataset, although at a lower efficacy. We establish the effectiveness of the proposed attacks using a suite of six machine-learning algorithms and five healthcare datasets. Finally, we present countermeasures against the proposed generic attacks that are based on tracking and detecting deviations in various accuracy metrics, and benchmark their effectiveness.

4. R. Azarderakhsh and **M. Mozaffari Kermani**, "High-performance two-dimensional finite field multiplication and exponentiation for cryptographic applications," IEEE Trans. Comput.-Aided Design Integr. Circuits Syst., vol. 34, no. 10, pp. 1569-1576, Oct. 2015.

   Finite field arithmetic operations have been traditionally used in different applications ranging from error control coding to cryptographic computations. Among these computations are normal basis multiplications and exponentiations which are utilized in efficient applications due to their advantageous characteristics and the fact that squaring (and subsequent powering by two) of elements can be obtained with no hardware complexity. In this paper, we present 2-D decomposition systolic-oriented algorithms to develop systolic structures for digit-level Gaussian normal basis multiplication and exponentiation over GF(2m). The proposed high-performance architectures are suitable for a number of applications, e.g., architectures for elliptic curve Diffie-Hellman key agreement scheme in cryptography. The results of the benchmark of efficiency, performance, and implementation metrics of such architectures through a 65-nm application-specific integrated circuit platform confirm high-performance structures for the multiplication and exponentiation architectures presented in this paper are suitable for high-speed architectures, including cryptographic applications.

5. R. Azarderakhsh, M. Mozaffari Kermani, S. Bayat-Sarmadi, and C. Lee, "Systolic Gaussian normal basis multiplier architectures suitable for high-performance applications," IEEE Trans. Very Large Scale Integr. (VLSI) Syst., vol. 23, no. 9, pp. 1969-1972, Sep. 2015.

   Normal basis multiplication in finite fields is vastly utilized in different applications, including error control coding and the like due to its advantageous characteristics and the fact that squaring of elements can be obtained without hardware complexity. In this brief, we present decomposition algorithms to develop novel systolic structures for digit-level Gaussian normal basis multiplication over GF(2m). The proposed architectures are suitable for high-performance applications, which require fast computations in finite fields with high throughputs. We also present the results of our application-specific integrated circuit synthesis using a 65-nm standard-cell library to benchmark the effectiveness of the proposed systolic architectures. The presented architectures for multiplication can result in more efficient and high-performance VLSI systems.

6. **M. Mozaffari Kermani,** N. Manoharan, and R. Azarderakhsh, "Reliable radix-4 complex division for fault-sensitive applications," IEEE Trans. Comput.-Aided Design Integr. Circuits Syst., vol. 34, no. 4, pp. 656-667, Apr. 2015.

   Complex division is commonly used in various applications in signal processing and control theory including astronomy and nonlinear RF measurements. Nevertheless, unless reliability and assurance are embedded into the architectures of such structures, the sub-optimal (and thus erroneous) results could undermine the objectives of such applications. As such, in this paper, we present schemes to provide complex number division architectures based on Sweeney, Robertson, and Tocher-division with error detection mechanisms. Different error detection architectures are proposed in this paper which can be tailored based on the eventual objectives of the designs in terms of area and time requirements, among which we pinpoint carefully the schemes based on recomputing with shifted operands to be able to detect faults based on recomputations for different operands in addition to the unified parity (simplified detecting code) and hardware redundancy approach. The design also implements a minimized look up table approach which favors in error detection based designs and provides high fault coverage with relatively-low overhead. Additionally, to benchmark the effectiveness of the proposed schemes, extensive error detection assessments are performed for the proposed designs through fault simulations and field-programmable gate array (FPGA) implementations; the design is implemented on Xilinx Spartan-6 and Xilinx Virtex-6 FPGA families.

7. R. Azarderakhsh, **M. Mozaffari Kermani**, and K. U. Jarvinen, "Secure and efficient architectures for single exponentiation in finite field suitable for high-performance cryptographic applications," IEEE Trans. Comput.-Aided Design Integr. Circuits Syst., vol. 34, no. 3, pp. 332-340, Mar. 2015.

   High performance implementation of single exponentiation in finite field is crucial for cryptographic applications such as those used in embedded systems and industrial networks. In this paper, we propose a new architecture for performing single exponentiations in binary finite fields. For the first time, we employ a digit-level hybrid-double multiplier proposed by Azarderakhsh and Reyhani-Masoleh for computing exponentiations based on square-and-multiply scheme. In our structure, the computations for squaring and multiplication are uniform and independent of the Hamming weight of the exponent; considered to have built-in resistance against simple power analysis attacks. The presented structure reduces the latency of exponentiation in binary finite field considerably and thus can be utilized in applications exhibiting high-performance computations including sensitive and constrained ones in embedded systems used in industrial setups and networks.

8. **M. Mozaffari Kermani**, K. Tian, R. Azarderakhsh, and S. Bayat-Sarmadi, "Fault-resilient lightweight cryptographic block ciphers for secure embedded systems," IEEE Embedded Sys., vol. 6, no. 4, pp. 89-92, Dec. 2014.

The development of extremely-constrained embedded systems having sensitive nodes such as RFID tags and nanosensors necessitates the use of lightweight block ciphers. Nevertheless, providing the required security properties does not guarantee their reliability and hardware assurance when the architectures are prone to natural and malicious faults. In this letter, error detection schemes for lightweight block ciphers are proposed with the case study of XTEA (eXtended TEA). Lightweight block ciphers such as XTEA, PRESENT, SIMON, and the like might be better suited for low-resource deeply-embedded systems compared to the Advanced Encryption Standard. Three different error detection approaches are presented and according to our fault-injection simulations, high error coverage is achieved. Finally, field-programmable gate array (FPGA) implementations of these proposed error detection structures are presented to assess their efficiency and overhead. The schemes presented can also be applied to lightweight hash functions with similar structures, making the presented schemes suitable for providing reliability to their light-weight security-constrained hardware implementations.

9. S. Bayat-Sarmadi, **M. Mozaffari Kermani**, and A. Reyhani-Masoleh, "Efficient and concurrent reliable realization of the secure cryptographic SHA-3 algorithm," IEEE Trans. Comput.-Aided Design Integr. Circuits Syst., vol. 33, no. 7, pp. 1105-1109, Jul. 2014.

   The secure hash algorithm (SHA)-3 has been selected in 2012 and will be used to provide security to any application which requires hashing, pseudo-random number generation, and integrity checking. In this paper, in order to provide reliable architectures for this algorithm, an efficient concurrent error detection scheme for the selected SHA-3 algorithm, i.e., Keccak, is proposed. To the best of our knowledge, effective countermeasures for potential reliability issues in the hardware implementations of this algorithm have not been presented to date. In proposing the error detection approach, our aim is to have acceptable complexity and performance overheads while maintaining high error coverage. In this regard, we present a low-complexity recomputing with rotated operands-based scheme which is a step-forward toward reducing the hardware overhead of the proposed error detection approach. Moreover, we perform injection-based fault simulations and show that the error coverage of close to 100% is derived. Furthermore, we have designed the proposed scheme and through ASIC analysis, it is shown that acceptable complexity and performance overheads are reached. By utilizing the proposed high-performance concurrent error detection scheme, more reliable and robust hardware implementations for the newly-standardized SHA-3 are realized.

10. **M. Mozaffari Kermani**, R. Azarderakhsh, C. Lee, and S. Bayat-Sarmadi, "Reliable concurrent error detection architectures for extended Euclidean-based division over GF(2^m)," IEEE Trans. Very Large Scale Integr. (VLSI) Syst., vol. 22, no. 5, pp. 995-1003, May 2014.

    The extended Euclidean algorithm (EEA) is an important scheme for performing the division operation in finite fields. Many sensitive and security-constrained applications such as those using the elliptic curve cryptography for establishing key agreement schemes, augmented encryption approaches, and digital signature algorithms utilize this operation in their structures. Although much study is performed to realize the EEA in hardware efficiently, research on its reliable implementations needs to be done. In this regard, this paper presents a new concurrent error detection (CED) scheme to provide reliability for the aforementioned sensitive and constrained applications. Our proposed CED architecture is a step forward toward more reliable architectures for the EEA algorithm architectures. Through simulations and based on the number of parity bits used, the error detection capability of our CED architecture is derived to be 100% for single-bit errors and close to 99% for the experimented multiple-bit errors. In addition, we present the performance degradations of the proposed approach, leading to low-cost and reliable EEA architectures.

IV. b. Digital Systems: Dorin Patru

David Herdzik, Holden Sandlar, Jesse Muszynski, Adam Spirer, Dorin Patru "SOAP – Sea Of Atomic Processors", Energy Efficient Networks of Computers Workshop, International Green and Sustainable Computing IEEE Conference, Las Vegas, NV 2015.

This paper proposes a massively parallel computer architecture appropriate for implementation in late and post silicon technologies. These technologies promise to integrate more than a billion components on a chip or other substrates, but of which some may fail temporarily or permanently. In the proposed architecture, programs and data are organized in entities that are created, exist, move, adapt, and share a sea of atomic processors. If component failures render one or more atomic processors not functional, the functional integrity of the system as a whole is not affected. The architecture maximizes the exploitation of instruction and thread level parallelisms inherently available in traditional programs. The paper presents the architecture's organization, communications protocols, and operation. Lower and upper bounds for the effective execution time of 100% sequential and 100% parallel code, respectively, are obtained using analytical methods. Further evaluation is performed using a few relevant examples. Although the proposed architecture shares traits with several known architectures, its organization, operation, and performance characteristics are unique.

IV. Electromagnetics: Jayanti Venkataraman

Funded by:
CSpeed, Syracuse NY
Tokyo Electron, Austin, TX

1. **Venkataraman J.** “Electromagnetics in Emerging Medical Technologies” Plenary Talk, EUROEM Symposium, London, UK, July 11-15, 2016

   The rapid advances in analog and digital technology have enabled electromagnetics to be applied in a wide range of medical therapies related to oncology, gastroenterology, ophthalmology, endocrinology etc. These are based on a variety of methodologies such as non-invasive diagnosis, continuous monitoring of physiological data, communication between implanted devices, communication to external devices, microwave imaging etc. In this paper, the state-of-art of electromagnetics in emerging medical technologies will be summarized. A few applications will be discussed in greater detail based on research at RIT.

2. Tsouri G, Zambita S. and **Venkataraman J**., “On the Benefits of Creeping Wave Antennas in Reducing Interference between Neighboring Wireless Body Area Networks”, IEEE Trans on Biomedical Circuits and Systems (accepted, to appear 2016)

   We consider the on-body, off-body, and body-to-body channels in wireless body area networks utilizing creeping wave antennas. Experimental setups are used to gather measurements in the 2.4 GHz band with body area networks operating in an office environment. Data packets providing received signal strength indicators are used to assess the performance of the creeping wave antenna in reducing interference at a neighboring on-body access point while supporting reliable on-body communications. Results demonstrate that creeping wave antennas provide reliable on-body communications while significantly reducing inter-network interference; the inter-network interference is shown to be 10dB weaker than the on-body signal. In addition, the inter-network interference when both networks utilize creeping wave antennas is shown to be 3dB weaker than the interference when monopole antennas are used.

3. Munuswamy C., Ganguly A. and **Venkataraman J**., “Design of Antennas for 3D Wireless Network-on-Chip with Micro-Fluidic Cooling Layers”, IEEE Antenna and Propagation Society International Symposium, Puerto Rico, June 27-July1, 2016.

   Recent trend in 3-D Network on a Chip (NoC) utilizing wireless interconnects to improve communication speeds have been successful. Liquid cooling channels introduced on top and bottom still leave the interior of the chip as ahot spot. In the present work, novel architecture of 3-D NoC is modeled in different configurations of embedded micro fluidic layers to address the interior heating. Wired interconnects through the fluidic layers is not possible, zig-zag antennas are implemented and placed in different configurations, to serve as wireless interconnects. The thermo-fluidic layers are modeled as channels of dielectric constant 1.75. Each antenna has been individually designed and tuned to resonate at 60 GHz with a return loss (RL) less than -10dB, using ANSYS High Frequency System Simulator (HFSS). The paper also discusses the transmission coefficients and shows low noise up to 10 GHz.

4. Khan A., **Venkataraman J.** and Lu Z., “Non-Crosstalk Light Propagation in Anisotropic Metamaterials Composed of Multilayered Metal-Insulator Stack”, IEEE Antenna and Propagation Society International Symposium, Puerto Rico, June 27-July1, 2016.

An interesting metamaterial Non-Crosstalk structure with anisotropic properties has been developed in the Nanoplasmonics and Metamaterials Research Lab at RIT. It is a cubical structure with Multilayer Metal-Insulator (MMI) stack-up, in the center of which are two groves cut orthogonal to each other. The dielectric properties of the structure developed analytically have shown this to be an Indefinite Isotropic Media (IAM) [1]. In the present work, the MMI structure has been developed using these analytical formulations. With a dipole antenna as source, it is shown that propagation occurs along one direction and not in the orthogonal direction.

5. Narde R. S., Lu Z. and **Venkataraman J**., "Trimmed DOE Lens and Gain Enhancement", IEEE Antenna and Propagation Society International Sym, Puerto Rico, June 27-July1, 2016.

   The RIT research group has developed, designed, constructed and tested a diffractive optical element (DOE) lens for gain enhancement and beam shaping. Although the lens is unique in that it is much thinner and lighter, the size proved to be much larger than the antenna dimensions. This paper presents a methodology for creating a more realistic size of the DOE lens with respect to the antenna dimensions by trimming the lens in one plane and obtaining the gain enhancement in each case. The simulation is performed in CST Microwave Studio.

6. Petersen E., Katta, V., and **Venkataraman J.,** "Propagation and Scattering in a Microwave Plasma Chamber", IEEE Antenna and Propagation Society International Symposium, Vancouver, Canada, July 19-23, 2015.

   The paper presents the analysis of propagation and scattering in a microwave plasma chamber. The chamber consists of a looped circular waveguide with the TE11 mode excited by the TE10 mode from a linear rectangular waveguide. The microwave power extracted through a slit along the cavity wall that is lined by quartz permeates the oxygen injected in the center and ionized by 50,000 volts hence creating plasma. The complexity of the scattering of the field through the quartz and propagating in the plasma provides several challenges to obtaining a uniform field distribution within the chamber.. A nonlinear Drude model of the plasma in CST (Computer Simulation Technology) has been developed to analyze the scattered field in the plasma region.

7. Adhyapak A., Sidley M. and **Venkataraman J.,** "Analytical model for real time, non-invasive estimation of blood glucose level", International IEEE Engineering in Medicine and Biology Conference, Chicago, August 25-29, 2014.

   The paper presents an analytical model to estimate blood glucose level from measurements made non-invasively and in real time by an antenna strapped to a patient's wrist. Some promising success has been shown by the RIT ETA Lab research group that an antenna's resonant frequency can track, in real time, changes in glucose concentration. Based on an in-vitro study of blood samples of diabetic patients, the paper presents a modified Cole-Cole model that incorporates a factor to represent the change in glucose level. A calibration technique using the input impedance technique is discussed and the results show a good estimation as compared to the glucose meter readings. An alternate calibration methodology has been developed that is based on the shift in the antenna resonant frequency using an equivalent circuit model containing a shunt capacitor to represent the shift in resonant frequency with changing glucose levels. Work under progress is the optimization of the technique with a larger sample of patients.

8. Torbitt C., Tomsic K., **Venkataraman J.,** Tsouri G., Laifenfeld M. and Dziatczak M. “Investigation of waveguide effects in intra-vehicular environments”, IEEE Antenna and Propagation Society International Symposium, Memphis, July 7-11, 2014

   Supporting intra-vehicular sensing using wireless communication is beneficial for eliminating wires and saving costs. The traditional approach is using transmit and receive antennas radiating into the car’s open space. Radiated signals are exposed to strong fading due to shadowing and the dynamic nature of the wireless channel. Preliminary experimental observations of the feasibility of propagating a signal over the surface of the car lead to the motivation of the present work. Simulations using CST microwave studio is used to determine the level of wave propagation through a layer of paint and compared to experimental results. A study has been performed for analyzing the surface wave hypothesis at different frequencies

9. Torbitt C., Lu Z., and **Venkataraman J**. “Beam shaping and Gain Enhancement using DOE Lens”, IEEE Antenna and Propagation Society International Sym, Memphis, July 7-11, 2014.

   The present work focuses on the design of a diffractive optical element (DOE) lens for the same purpose, the advantage being that it is much thinner lighter and easy to fabricate. Gain enhancement is illustrated by modeling the DOE lens in CST microwave studio and placing it in front of different antennas. The antennas consist of a horn, slotted waveguide, and microstrip patch array. Beam shaping and focusing is clearly illustrated. It is seen that the size of the lens is proportional to gain increase which can be as high as 18dB enhancement for a 45-GHz horn antenna. The lens, which is made from rexolite, can be easily fabricated and experimental validation of simulated results is under progress.

10. Giri D.V. and **Venkataraman J.,** “Therapeutic and diagnostic uses of Electromagnetic Energy”, AMEREM 2014, Electromagnetics Conference, Albuquerque, July 27-31, 2014

   The electromagnetic (EM) spectrum ranging from DC to Gamma rays and beyond is a vast natural resource that has been very valuable for mankind. With the rapid advances of medical technology, Radio Frequency (RF) techniques are becoming increasingly popular for a variety of applications such as non-invasive diagnosis, continuous monitoring of physiological data, communication between implanted devices, and communication to external devices. In this paper, we review therapeutic uses of EM energy.

V. MEMS: Sergey Lyshevski

Journal Articles

1. **S. E. Lyshevski**, "Control of dynamic *microsystems*," *International Journal of Systems Science*, vol. 45, no. 2, pp. 1-11, 2014.

   This paper formulates and solves control problems for nonlinear microsystems which comprise micro-electromechanical devices, micromachined transducers and microelectronics. We perform a consistent dynamic analysis and coherent designs with a minimum level of simplifications using high-fidelity mathematical models. The proposed methodology enables practical implementation for multi-input/multi-output systems due to overall conceptual consistency, design coherence, computational efficiency, algorithmic effectiveness and hardware simplicity. Various issues in nonlinear analysis and control are examined and experimentally verified substantiating design concepts for high-performance microsystems. The reported findings are demonstrated for a proof-of-concept closed-loop electrostatic microactuator.

2. **S. E. Lyshevski**, "Microstepping and high-performance control of permanent-magnet stepper motors," *Journal Energy Conversion and Management*, vol. 85, pp. 245-253, 2014.

   We examine the problem of control of high-performance drives and servos with permanent-magnet stepper motors. Control of electromechanical systems implies control and optimization of electromechanical transductions and energy conversion. Robust spatio-temporal control algorithms are designed to ensure high efficiency, high-precision microstepping and optimal performance. The system stability, robustness and control design are examined applying an admissibility concept. Nonlinear control guarantees optimal energy conversion in expanded operating envelopes. Our analytic designs are substantiated and verified.A proof-of-concept system is tested and characterized. The high electromagnetic torque and high precision microstep angular positioning simplify kinematics, enables efficiency, ensures direct-drive capabilities, reduces complexity, etc. For four-phase permanent magnet stepper motors, one may ensure up to 256 microsteps within a 1.8- full step. High efficiency and accurate 2.454x10-4 rad positioning (25,600 microsteps per revolution) are achieved with high electromagnetic and holding torques. To guarantee high efficiency, optimality and enabled energy conversion capabilities, electromechanical energy conversion and high electromagnetic torque are achieved by applying soft balanced phase voltages. The ripple and friction torques are minimized. The fundamental findings, technology-centric design and experimental results are reported.

Conference Papers (Refereed)

1. I. P. Puchades, L. F. Fuller and **S. E. Lyshevski**, "Integrated nanotechnology, electronics and microsystems: Sensing paradigms and transformative MEMS technologies," *Proc. IEEE Nanotechnology Conf.*, Toronto, pp. 207-210, 2014.

We document transformative research, practical engineering solutions and enabling sensing technologies. Microsystems integrate nanotechnology, microelectronics and micromachining. Micro-electromechanical systems (MEMS) are used in various applications. In aerospace, automotive, energy, manufacturing, medical, naval and other systems, autonomous MEMS measure physical quantities, process the data, transmit information and ensure control. Acceleration, electromagnetic fields, flow rate, position, pressure, temperature, velocity, viscosity and other physical quantities can be measured. MEMS enable biotechnology and medicine. Microsystems measure impurities, analyze bio and chemical compositions of liquids and gasses, perform DNA profiling, analyse genes and proteins, etc. Using recent nanotechnology-enabled solutions, we use application-specific nanostructured sensing materials and *fabrics*. A consistent device-level integration of nanostructured materials and nanoscaled microelectronic is ensured. Modular MEMS include self-sustainable energy sources, energy storage solution and energy management. We design, fabricate, test and characterize functional autonomous microsystems.

2. I. P. Puchades, M. Hobosyan, L. F. Fuller, F. Liu, S. Thakur, K. S. Martirosyan and **S. E. Lyshevski**, “MEMS microthrusters with nanoenergetic solid propellants,” *Proc. IEEE Nanotechnology Conf.*, Toronto, pp. 83-86, 2014.

   Solid propellants are used in various flight and underwater systems as well as in propulsion platforms. Micromachining, microelectromechanical systems (MEMS) and automatic dispensing of high-energy-density nanoenergetic materials are examined for current and next generation of application-specific flight and underwater platforms. The integrated MEMS-technology microthrusters with the optimized-by-design nanostructured propellants ensure the expected thrust-to-weight and thrust-to-power ratios, specific impulse, effective exhaust velocity, thrust, energy density, controlled combustion, etc. The flight-proven propulsion and micromachining technologies are suitable in a wide range of applications, such as payload delivery, stabilization, guidance, navigation, etc. Compared with mono- and bi-propellant, ion, laser, plasma, Hall-effect and other thrusters, our solution ensures fabrication simplicity, affordability, robustness, integration, compatibility, safety, etc. The experimental substantiation, evaluation and characterization of fabricated proof-of-concept devices with nanoenergetic propellants are reported.

3. **S. E. Lyshevski**, L. Reznik, T. C. Smith, M. A. Beisenbi, J. Y. Jarasovna, N. S. Mukataev and A. N. Omarov, “Estimates and measures of data communication and processing in nanoscaled classical and quantum physical systems,” *Proc. IEEE Nanotechnology Conf.*, Toronto, pp. 1044-1047, 2014.

   This paper studies fundamentals of classical, classical-quantum and quantum information technologies to advance sensing, data acquisition and computing. The overall goal is to define, analyze and evaluate classical and quantum mechanical information measures pertained to data processing by low-power nanoelectronic devices, nanoICs, nanowaveguides, CMOS nanophotonics, etc. Electronic, optoelectronic and photonic systems operate on the electron and photon-induced transductions. There are fundamental differences in physics, arithmetics, device- and system-level solutions as electrostatic and quantum phenomena are utilized. This paper analyzes multi-physics quantum«classical processing. We enable a knowledge base in cognizant areas across computer science and engineering. Our findings enable existing and future communication, sensing, information fusion, computing and processing platforms. Consistent tools and practical schemes facilitate developments of novel engineering solutions, technical readiness, technological capabilities and commercialization capacities.

4. I. P. Puchades, L. F. Fuller and **S. E. Lyshevski**, "CMOS-compatible thermally actuated MEMS viscosity sensor with aluminum on silicon plate," *Proc. NanoTech Conf.*, Washington, DC, vol. 2, pp. 37-40, 2014.

   In the fields of rheology and tribiology, viscosity is one of the most important factors used to characterize fluid properties. In the automotive, aerospace, energy, naval, transportation and other applications, oil is used as an engine and motion devices lubricant. It is imperative that the oil viscosity is kept within a specific range to provide the needed functionality, safety, high performance, etc. The higher the viscosity, the more resistance the liquid creates and the harder to operate for machines. These lead to low efficiency, temperature increase, low fuel economy, damages, etc. If the viscosity is too low, oil will not provide sufficient protection leading to wearing and unsafety.

5. I. P. Puchades, M. Hobosyan, L. F. Fuller, F. Liu, S. Thakur, K. S. Martirosyan and **S. E. Lyshevski**, "Nanotechnology-enabled microthrusters: Nanoenergetic materials and MEMS paradigm," *Proc. NanoTech Conf.*, Washington, DC, vol. 2, pp. 29-32, 2014.

   We study microthrusters which can be used in various flight and underwater platforms. The MEMS-technology thrusters with Al/I2O5 and Al/Bi2O3 nanostructured energetic composites increase thrust-to-weight ratio and energy density, thereby ensuring enabling capabilities. The integrated micromachining ensures overall technology compatibility, scalability, simplicity, affordability, robustness, etc. These lead to advantages as compared to conventional solutions. The MEMS-technology microthrusters with solid-fuel are suitable in a wide range of applications, such as payload delivery, stabilization, guidance, navigation and other platforms.

6. T. C. Smith and **S. E. Lyshevski**, "Nanotechnology enabled photovoltaics and electronics for high-power-density energy systems," *Proc. NanoTech Conf.*, Washington, DC, vol. 3, pp. 335-338, 2014.

   For portable energy systems, this paper examines nanotechnology-enabled high-power and high-energy density microelectronics, power electronics, energy sources, and energy storage solutions. These energy systems are used in various applications including aerospace, biomedical, communication, electronics, micro-electromechanical systems (MEMS), robotics, etc. Proof-of-concept autonomous power systems are designed, and practical solutions are substantiated. We perform research and technology developments in the design of efficient energy harvesting, energy management, and energy storage solutions. To guarantee modularity and compatibility, the following components and modules are integrated: (1) Low-power microelectronics; (2) High-power density power electronics with high-current, high-voltage and high-frequency power MOSFETs; (3) High-efficiency energy harvesting sources such as solar cells and electromagnetic generators; (4) High specific energy and power density electrochemical energy storage devices; (5) Optimal energy management systems. The most advanced technology-proven nanoscale microelectronics, MEMS sensors, and energy conversion solutions are studied. The *modular* design, enabling topologies and optimization schemes result in high performance micro- and mini-scale energy systems.

7. **S. E. Lyshevski** and L. Reznik, “Information-theoretic estimates of classical and quantum communication and processing at nanoscale,” *Proc. NanoTech Conf*., Washington, DC, vol. 3, pp. 25-28, 2014.

   This paper examines fundamentals of classical, *hybrid* and quantum information technologies which are the bases of computer science and computer engineering. We define, analyze and evaluate classical and quantum-mechanical information measures pertained to communication and processing at nanoscale. The *macroscopic* and *microscopic* physical communication and processing platforms and hardware are considered. *Macroscopic* and *microscopic* systems operate on the electron- and photon-induced transductions. However, conventional electrostatic and quantum processing are fundamentally distinct. There are major differences in device physics, utilized phenomena, device- and system-level solutions, arithmetics, software and hardware solutions, etc. This paper contributes to design and analysis of multi-physics quantum«classical communication and processing. We advance a knowledge base in cognizant areas across disciplines. Our findings enable existing and future communication, sensing, information fusion, computing and processing platforms. These enable technical readiness, technological capabilities and commercialization capacities by developing relevant tools, methods and practical schemes.

8. N. Nuzdina, Z. Mansurov, E. Aliev and **S. E. Lyshevski**, “Premises of communication and processing on photons in natural and engineering systems: Implication to science and high-technology market,” *Proc. NanoTech Conf*., Washington, DC, vol. 2, pp. 447-450, 2014.

   In various photonic, optoelectronic and microelectronic systems, new communication and processing solutions are under intensive studies. New technologies emerge to design, fabricate and commercialize communication, processing and sensing platforms. Transformative fundamental findings, engineering developments and practical technologies are implemented and substantiated. New proof-of-concept multiphysics photonic and optoelectronic *macroscopic*, *mesoscopic* and *microscopic* systems are designed, fabricated, tested, characterized and demonstrated reaching a sufficient technology readiness level. Our goal is to further enhance physical foundations, enable engineering premises and advance information technologies of classical, quantum and *mixed* communication and processing. This paper examines emerging quantum-enabled and quantum technologies aimed for communication and data processing. The studied premises: (i) Unify and enable concepts of computer science, engineering and technologies; (ii) Consistent with quantum informatics, communication, computing and processing schemes; (iii) Comply with emerged software and hardware solutions; (iv) Exhibit sufficient technology readiness and technology transfer capabilities.

VI. Optoelectronics and Nanophotonics: Jing Zhang

Funded by:
Office of Naval Research
New York State Energy Research and Development Authority

Refereed Journal Publications

1. Y. K. Ooi, and J. Zhang, "Design analysis of phosphor-free monolithic white light-emitting-diodes with InGaN/ InGaN multiple quantum wells on ternary InGaN substrates", AIP Advances, vol. 5, Art. 057168, May 2015.

   Phosphor-free monolithic white light emitting diodes (LEDs) based on InGaN/ InGaN multiple quantum wells (MQWs) on ternary InGaN substrates are proposed and analyzed in this study. Simulation studies show that LED devices composed of multi-color-emitting InGaN/ InGaN quantum wells (QWs) employing ternary InGaN substrate with engineered active region exhibit stable white color illumination with large output power (~ 170 mW) and high external quantum efficiency (EQE) (~ 50%). The chromaticity coordinate for the investigated monolithic white LED devices are located at (0.30, 0.28) with correlated color temperature (CCT) of ~ 8200 K at J = 50 A/cm^2. A reference LED device without any nanostructure engineering exhibits green color emission shows that proper engineered structure is essential to achieve white color illumination. This proof-of-concept study demonstrates that high-efficiency and cost-effective phosphor-free monolithic white LED is feasible by the use of InGaN/ InGaN MQWs on ternary InGaN substrate combined with nanostructure engineering, which would be of great impact for solid state lighting.

2. C. Liu, Y. K. Ooi, and J. Zhang, "Proposal and physics of AlInN-delta-GaN quantum well ultraviolet lasers", J. Appl. Phys., vol. 119, Art. 083102, February 2016.

   The use of AlInN-delta-GaN quantum wells(QWs) active region for ultraviolet(UV) laser with wavelength (λ) ~ 250–300 nm was proposed and investigated in this work. The design of active region consists of 24 Å staggered $Al_{0.91}In_{0.09}N/Al_{0.82}In_{0.18}N$ layers with a 3 Å lattice-matched GaN delta layer, which enables dominant conduction band (C) to heavy hole (HH) subband transition. In addition, the insertion of the ultra-thin delta GaN layer will strongly localize the electron-hole wave functions toward the center of theQW, which leads to large transverse electric (TE) polarized optical gain. In comparison to the use of a conventional AlGaNQW system, the proposed AlInN-delta-GaN QWstructure results in ~3 times improvement in TE-gain at 255 nm. By tuning the delta-GaN thickness, the TE-polarized optical gain up to 3700 cm^{-1} can be obtained for λ ~ 280–300 nm, which is very promising to serve as an alternative active region for high-efficiency UV lasers.

Refereed Conference Publications

1. Y. K. Ooi, and J. Zhang, "Phosphor-free Monolithic High-Efficiency White Light-Emitting-Diodes on Ternary InGaN Substrates", in *Proc. of the IEEE/OSA Conference on Lasers and Electro-Optics (CLEO) 2015*, San Jose, CA, May 2015.
   Phosphor-free monolithic high-efficiency tunable white LEDs are realized on ternary InGaN substrates. This proof-of-concept study demonstrates that high quantum efficiency and stable white color emission are achieved by using ternary substrates and correctly-engineered device structures.

2. C. Liu, Y. K. Ooi, and J. Zhang, "Large TE-polarized optical gain from AlInN-delta-GaN quantum well for ultraviolet lasers", Proc. of the SPIE Photonics West 2016, San Francisco, CA, February 2016.

   Ultraviolet (UV) lasers with wavelength (λ) < 300 nm have important applications in free-space communication, water/air purification, and biochemical agent detection. Conventionally, AlGaN quantum wells (QWs) are widely used as active region for UV lasers. However, high-efficiency electrically injected mid-UV lasers with λ ~ 250-300 nm are still very challenging as the corresponding AlGaN QWs suffer from severe band-mixing effect due to the presence of the valence sub-band crossover between the heavy-hole (HH) and crystal-field split off (CH) sub-bands, which would result in very low optical gain in such wavelength regime.

   Therefore, in this work, we propose and investigate the use of AlInN material system as an alternative for mid-UV lasers. Nanostructure engineering by the use of AlInN-delta-GaN QW has been performed to enable dominant conduction band – HH sub-band transition as well as optimized electron-hole wave function overlap. The insertion of the ultra-thin delta-GaN layer, which is lattice-matched to Al0.82In0.18N layer, would localize the wave functions strongly toward the center of the active region, leading to large transverse electric (TE) polarized optical gain (g^{TE}) for λ~ 250- 300 nm. From our finding, the use of AlInN-delta-GaN QW resulted in ~ 3-times enhancement in TE-polarized optical gain, in comparison to that of conventional AlGaN QW, for gain media emitting at ~ 255 nm. The peak emission wavelength can be tuned by varying the delta layer thickness while maintaining large TE gain. Specifically, g^{TE} ~ 3700 cm-1 was obtained for λ ~ 280-300 nm, which are very challenging for conventional AlGaN QW active region.

VII. a. Robotics: Ferat Sahin

Funded by:
Protequus LLC
MKS ENI Products

1. Eyup Cinar and **Ferat Sahin**, "Development of a novel nanoindentation technique by utilizing a dual-probe, AFM system", *Beilstein Journal of Nanotechnology*, volume 6, issue 1, pp. 2015 – 2027, October 2015.

   A novel instrumentation approach to nanoindentation is described that exhibits improved resolution and depth sensing. The approach is based on a multi-probe scanning probe microscopy (SPM) tool that utilizes tuning-fork based probes for both indentation and depth sensing. Unlike nanoindentation experiments performed with conventional AFM systems using beam-bounce technology, this technique incorporates a second probe system with an ultra-high resolution for depth sensing. The additional second probe measures only the vertical movement of the straight indenter attached to a tuning-fork probe with a high spring constant and it can also be used for AFM scanning to obtain an accurate profiling. Nanoindentation results are demonstrated on silicon, fused silica, and Corning Eagle Glass. The results show that this new approach is viable in terms of accurately characterizing mechanical properties of materials through nanoindentation with high accuracy, and it opens doors to many other exciting applications in the field of nanomechanical characterization.

2. Shitij Kumar and Ferat **Sahin**, "A framework for a real time intelligent and interactive brain computer interface", *Computer and Electrical Engineering Journal*, *Elsevier*, vol. 43, issue 1, pages 193 - 214, April 2015.

   This research proposes a framework for a real time implementation of a Brain Computer Interface (BCI). This interface is designed with a future objective of providing a testing platform as an interactive and intelligent Image Search and Retrieval tool that allows users, disabled or otherwise, to browse and search for images using non-invasive electroencephalography (EEG) signals. As a proof of concept, a prototype system was designed and implemented to test real time data collection and navigation through the interface by detection and classification of event-related potentials (ERPs). A comparison of different feature extraction methods and classifiers for the detection of ERPs is performed on a standard data set to determine the best fit for the real time implementation of the BCI. The preliminary results of the real time implementation of the prototype BCI system are quantified by the success rate of the user/subject in navigating through the interface and spelling a search keyword using the mental-typewriter Hex-O-Speller.

3. Selman Uguz, Ugur Sahin and **Ferat Sahin**, "Edge detection with fuzzy cellular automata transition function optimized by PSO", *Computer and Electrical Engineering Journal*, *Elsevier*, vol. 43, issue 1, pages 180 - 192, April 2015.

   In this paper we discuss the application of two-dimensional linear cellular automata (CA) rules with the help of fuzzy heuristic membership function to the problems of edge detection in image processing applications. We proposed an efficient and simple thresholding technique of edge detection based on fuzzy cellular automata transition rules optimized by Particle Swarm Optimization method (PSO). Finally, we present some results of the proposed linear rules for edge detection to the selected 22 images from the Berkeley Segmentation Dataset (BSDS) and compare with some classical Sobel and Canny results. Also, Baddeley Delta Metric (BDM) is used for the performance index to compare the results.

4. Aaron Wilbe, **Ferat Sahin**, and Ugur Sahin, "A Framework for Intelligent Creation of Edge Detection Filters", *Proceedings of 2015 IEEE Systems, Man, and Cybernetics Conference,* Hong Kong, October 2015.

   In this paper, we introduce a framework for a system which intelligently assigns an edge detection filter to an image based only on features taken from the image. The system has four parts, the training set which consists of an image and its edge image ground truth, feature extraction, training filter creation, and system training. A prototype system of this framework is given. In the system feature extraction is performed using a GIST methodology which extracts color, intensity, and orientation information as features. The set of image features are used as the input to a single hidden layer feed forward neural network trained using back propagation. The system trains against a set of linear Cellular Automata filters which are determined to best solve the edge image according to the Bad delay Delta Metric. This metric takes into account false positives and false negative error by scaling the errors relative to the perpendicular distance that they are off from the ground truth. The system was trained and tested against the images from the Berkeley Segmentation Database. The results from the testing indicate that the system performs better than standard methods in many cases but on the whole is only on par across a wide range of images.

5. Eyup Cinar and **Ferat Sahin,** "A system of systems analysis of a multi-probe SPM system", in the Proceedings of 2015 10th System of Systems Engineering Conference (SoSE2015), pp. 117 – 121, June 2015.

   In this paper, we introduce a multi-probe Scanning Probe Microscopy (SPM) tool in the context of system of systems (SoS) concepts. The tool exhibits strong characteristics of SoS such as interoperability, integration and independency of each individual system. Each probe terminal constitutes an independent scanning system that can operate individually. The interoperability of the systems through signal exchange bring strong advantages and help users in order to design innovative applications that would not be easily achievable when a single system is used. As an independent system, each probe terminal includes its own controller and feedback mechanism for precise operation which is controlled by individual software running on control PCs. After introducing the overall system, we briefly mention one of the innovative real-world applications that we have been currently working on in an effort to show the strength of SoS engineering and filling the gap between theory and practice.

6. Brian Stevenson and **Ferat Sahin**, "Modeling and dynamic control for a hexapod robot", Proceedings of 2015 10th System of Systems Engineering Conference (SoSE2015), pp. 304 - 309, June 2015.
   In the every expanding field of robotics, mobile robots come in a two primary variations: wheeled and legged. This paper will focus on the latter, specifically a hexapod with a circular body that has its six legs distributed axisymmetrically around the body. The core goal of the project discussed here is to allow the robot to dynamically change foot placement based on an input vector in addition to controlling the position and orientation of the body. Specific attention is also given to a simulation model that can mimic this control of the robot in a virtual environment. Having a high level of control enhances the robot's ability to move in a very smooth and purposeful manner.

7. Girish Chandrashekar, **Ferat Sahin**, "A survey on feature selection methods", *Computers & Electrical Engineering*, vol. 40, issue 1, pages 16-28, 2014.

   Plenty of feature selection methods are available in literature due to the availability of data with hundreds of variables leading to data with very high dimension. Feature selection methods provides us a way of reducing computation time, improving prediction performance, and a better understanding of the data in machine learning or pattern recognition applications. In this paper we provide an overview of some of the methods present in literature. The objective is to provide a generic introduction to variable elimination which can be applied to a wide array of machine learning problems. We focus on Filter, Wrapper and Embedded methods. We also apply some of the feature selection techniques on standard datasets to demonstrate the applicability of feature selection techniques.

8. Ugur Sahin, Selman Uguz, **Ferat Sahin**, "Salt and pepper noise filtering with fuzzy-cellular automata", *Computers & Electrical Engineering*, vol. 40, issue 1, pages 59-69, 2014.

   A new image denoising algorithm is proposed to restore digital images corrupted by impulse noise. It is based on two dimensional cellular automata (CA) with the help of fuzzy logic theory. The algorithm describes a local fuzzy transition rule which gives a membership value to the corrupted pixel neighborhood and assigns next state value as a central pixel value. The proposed method removes the noise effectively even at noise level as high as 90%. Extensive simulations show that the proposed algorithm provides better performance than many of the existing filters in terms of noise suppression and detail preservation. Also, qualitative and quantitative measures of the image produce better results on different images compared with the other algorithms.

9. Eyup Cinar and **Ferat Sahin**, " New approach for nanoindentation using multiprobe AFM system", *Proceedings of the 14th IEEE International Conference on Nanotechnology (IEEE-NANO)*, pages 49 – 53, Toronto, Canada, August 2014.

   In nanoindentation, the accuracy of obtained data is highly depended on the limitations of the system that the measurements are performed with. In this paper for the first time in the literature, we present a new nanoindentation approach with a system that eliminates the major problems encountered with standard AFM or nanoindentation systems. We present the superior properties of our system and also discuss the current issues with standard systems. The end goal of this research work is to utilize the new approach for accurate mechanical characterization of soft materials which will be used in biological cell mechanics applications.

10. Andrew Phillips and **Ferat Sahin**, "A comparison of chatter attenuation techniques applied to a twin rotor systems", *Proceedings of 2014 IEEE Systems, Man, and Cybernetics Conference, pages 3265-3271*, San Diego, Ca, USA, October 2014.

    The twin rotor MIMO system (TRMS) is a helicopter-like system that is restricted to two degrees of freedom, pitch and yaw. It is a complicated nonlinear, coupled, MIMO system used for the verification of control methods and observers. This paper compares the ability of three adaptive sliding mode controllers (SMC) to suppress chattering. Once the design is complete the controllers are implemented in simulation and experimentally. The performance of the controllers is compared against a PID controller and other controllers in the literature. The ability of the sliding mode controllers (SMC) to suppress chattering is also explored.

11. Andrew Phillips and **Ferat Sahin**, "Optimal control of a twin rotor MIMO system using LQR with integral action", *Proceedings of the World Automation Congress (WAC 2014)*, pp. 114 – 119, Waikoloa, Hawaii, 3 – 7 August 2014.

    The twin rotor MIMO system (TRMS) is a helicopter-like system that is restricted to two degrees of freedom, pitch and yaw. It is a complicated nonlinear, coupled, MIMO system used for system identification, the verification of control methods and observers. This paper details the design procedure for a suboptimal tracking controller using a linear quadratic regulator (LQR) with integral action. It was found that the LQR controller with integral action (LQI) provided performance superior to existing optimal controllers in the literature.

12. Ryan Bowen, **Ferat Sahin,** Aaron Radomski, and Daniel Sarosky, "Embedded one-class classification on RF generator using Mixture of Gaussians", *Proceedings of 2014 IEEE Systems, Man, and Cybernetics Conference*, pp. 2657-2662, San Diego, USA, October 2014.

    In this paper we apply a specific machine learning technique for classification of normal and not-normal operation of RF (Radio Frequency) power generators. Pre-processing techniques using FFT and bandpower convert time-series system signatures into single feature vectors. These feature vectors are modeled using k-component Mixture of Gaussians (MoG) where components and corresponding parameters are learned using the Expectation Maximization (EM) algorithm. Data is obtained from three different generator models operating under normal and multiple different not-normal conditions. Exploration into algorithmic parameter effects is conducted and empirical evidence used to select sub-optimum parameters. Robust testing is reported to achieve a 3s classification accuracy of 95.91% for the targeted RF generator. Additionally, a custom C++ library is implemented to utilize the learned model for accurate classification of time-series data within an embedded environment such as a RF generator. The embedded implementation is reported to have a small storage footprint, reasonable memory consumption and overall fast execution time.

VIII b. Robotics: Sildomar Monteiro

Funded by: Amazon web services (AWS)

1. T. Peynot, S. T. Monteiro, A. Kelly, and M. Devy, "Editorial: Special issue on alternative sensing techniques for robot perception," *Journao of Field Robotics*, vol. 32, no. 1, 2015.

   Perception based on the most commonly used sensors such as visual cameras and laser range finders (or LIDARs) has enabled major achievements in field robotics. Stanley and Boss won DARPA Grand Challenges using almost exclusively cameras and LIDARs (albeit many of them). The Opportunity rover, using only cameras for navigation, recently broke the off-Earth driving record, with a distance of more than 40km. However, the capabilities of state-of-the-art robotic systems have remained largely restricted by the intrinsic limitations of these sensors. Boss conquest of the DARPA Urban Challenge was temporarily compromised by the detection of a dust cloud by one of its LIDARs. Opportunity's glorious run came close to a premature ending when its cameras proved insufficient to predict that its wheels would get stuck in a sand dune that looked identical to many traversed thus far. These traditional sensors have often become insufficient when developing autonomous platforms that should operate for extended periods of time and in ever more challenging environments and conditions, e.g. limited visibility due to dust or fog. Complex and varied robotic applications may also require richer environment models than can be generated with only these traditional sensors. All these considerations have led to increased interest in alternative sensing modalities in recent years. To sense the environment, alternative sensors use physical principles that are distinct from those used by traditional robotic sensors, and may operate at various electromagnetic frequencies outside the visible spectrum. Examples include radars of various types, thermal cameras, hyperspectral and multispectral cameras, and sonars. The use of these sensors for robotic perception has allowed robots to operate in conditions that were previously infeasible and had to be avoided. Robots can navigate through smoke or at night with infrared imaging, or track roads in a dust storm using millimeter-wave radars. This sensory capability has also opened up a number of new robotic applications (e.g., automatic geological analysis using hyperspectral cameras, sonar mapping of oil rigs, eddy current inspection of nuclear boilers), in which alternative sensors are often combined with traditional robotic sensors to provide enhanced discrimination power and higher perception integrity. This special issue presents outstanding results on novel robotic perception concepts motivated by use of alternative sensing in challenging applications and environments.

2. N. Ahsan, S. Scheding, **S. T. Monteiro**, R. Leung, C. McHugh, and D. Robinson, "Adaptive sampling applied to blast-hole drilling in surface mining," *International Journal of Rock Mechanics and Mining Sciences*, vol. 75, pp. 244–255, 2015

This paper describes an application of adaptive sampling to geology modeling with a view of improving the operational cost and efficiency in certain surface mining applications. The objectives are to minimize the number of blast holes drilled into, and the accidental penetrations of, the geological boundary of interest. These objectives are driven by economic considerations as the cost is, firstly, directly proportional to the number of holes drilled and secondly, related to the efficiency of target material recovery associated with excavation and blast damage. The problem formulation is therefore motivated by the incentive to learn more about the lithology and drill less. The principal challenge with building an accurate surface model is that the sedimentary rock mass is coarsely sampled by drilling exploration holes which are typically a long distance apart. Thus, interpolation does not capture adequately local changes in the underlying geology. With the recent advent of consistent and reliable real-time identification of geological boundaries under field conditions using measure-while-drilling data, we pose the local model estimation problem in an adaptive sampling framework. The proposed sampling strategy consists of two phases. First, blast-holes are drilled to the geological boundary of interest, and their locations are adaptively selected to maximize utility in terms of the incremental improvement that can be made to the evolving spatial model. The second phase relies on the predicted geology and drills to an expert based pre-specified standoff distance from the geological boundary of interest, to optimize blasting and minimize its damage. Using data acquired from a coal mine survey bench in Australia, we demonstrate that adaptively choosing blast-holes in Phase 1 can minimize the total number of holes drilled to the top of the coal seam, as opposed to random hole selection, whilst optimizing blasting by maintaining a reasonable compromise in the error in the stopping distances from the seam. We also show that adaptive sampling requires, for accurate estimation, only a fraction of the holes that were initially drilled for this particular dataset.

3. T. M. Sands, D. Tayal, M. E. Morris, and **S. T. Monteiro**, "Robust stock value prediction using support vector machines with particle swarm optimization," in 2015 IEEE Congress on Evolutionary Computation (CEC), 2015, pp. 3327–3331.

   Attempting to understand and characterize trends in the stock market has been the goal of numerous market analysts, but these patterns are often difficult to detect until after they have been firmly established. Recently, attempts have been made by both large companies and individual investors to utilize intelligent analysis and trading algorithms to identify potential trends before they occur in the market environment, effectively predicting future stock values and outlooks. In this paper, three different classification algorithms will be compared for the purposes of maximizing capital while minimizing risk to the investor. The main contribution of this work is a demonstrated improvement over other prediction methods using machine learning; the results show that tuning support vector machine parameters with particle swarm optimization leads to highly accurate (approximately 95%) and robust stock forecasting for historical datasets.

VIII. a. Semiconductor Devices: Karl Hirschman

Funded by:
Corning Incorporated
NYSTAR Center for Emerging & Innovative Sciences (CEIS).

1. T. Mudgal, N. Walsh, R.G. Manley, and **K.D. Hirschman**, "Passivation and Annealing for Improved Stability of High Performance IGZO TFTs," MRS Proceedings, 1692 mrss14-1692-cc12-02 (2014) / DOI: http://dx.doi.org/10.1557/opl.2014.906

The influence of annealing ambient conditions and deposited passivation materials on indium-gallium-zinc-oxide (IGZO) thin-film transistor (TFT) performance is investigated. Results from annealing experiments confirm that a nominal exposure to oxidizing ambient conditions is required, which is a function of temperature, time and gas environment. Nitrogen anneal with a controlled air ramp-down provided the best performance devices with a mobility (μ_{sat}) of 13 $cm^2/V \cdot s$ and subthreshold slope (SS) of 135 mV/dec, with negligible hysteresis. Plasma-deposited passivation materials including sputtered quartz and PECVD SiO_2 demonstrated a significant increase in material conductivity, which was not significantly reversible by an oxidizing ambient anneal. E-beam evaporated Al_2O_3 passivated devices that were annealed in air at 400 °C exhibited demonstrated improvements in stability over non-passivated devices. BCB passivated devices that were annealed in air at 250 °C also demonstrated positive results.

2. T. Mudgal, N. Walsh, N. Edwards, R.G. Manley, and **K.D. Hirschman**, "Interpretation of Defect States in Sputtered IGZO Devices Using I-V and C-V Analysis," ECS Trans. 64 (10) 93-100 (2014) / DOI: 10.1149/06410.0093ecst

Capacitance-voltage (C-V) analysis is a valuable tool in separating the influence of material and interface defects from other factors that influence transistor operation. Thin-film transistors and interdigitated capacitors fabricated using sputtered IGZO have been studied to enhance the interpretation of defect states. Interdigitated capacitors are representative of the TFT channel region, and large-area designs provide a high capacitance swing from depletion to accumulation. Alumina was applied for back channel passivation, with annealing performed at 400 °C in oxidizing ambient conditions. Both I-V and C-V results were used with TCAD device simulation to develop a refined material and device model.

3. T. Mudgal, N. Walsh, R.G. Manley, and **K.D. Hirschman**, "Impact of Annealing on Contact Formation and Stability of IGZO TFTs," ECS J. Solid State Sci. Technol. 2014 volume 3, issue 9, Q3032-Q3034 (2014) / DOI: 10.1149/2.006409jss

Annealing processes were investigated on Indium-Gallium-Zinc-Oxide (IGZO) thin-film transistors (TFTs). Molybdenum and aluminum were used as contact metals which defined the working source/drain electrodes. Annealing was performed either pre-metal or post-metal deposition, in various gas ambient conditions including air, oxygen, nitrogen, forming gas (5% H_2 in N_2) and vacuum. Pre-metal annealing in air ambient resulted in similar I-V characteristics on Mo-contact and Al-contact devices. A post-metal anneal for Mo-contact devices resulted in higher on-state current and steeper subthreshold slope, whereas the Al-contact devices experienced severe degradation suggesting the formation of an AlO_X interface layer. Oxidant exposure during anneal was vital for controlling the electronic properties of IGZO. A post-metal anneal at 400 °C in N_2 followed by an air ambient ramp-down yielded Mo-contact devices with channel mobility μ_{sat} ~ 8.5 cm^2/V·s and subthreshold swing *SS* ~ 200 mV/dec. Electron-beam evaporated alumina was used for back-channel passivation which resulted in improved stability at the expense of slight degradation in device performance.

4. T. Mudgal, N. Walsh, R.G. Manley, and **K.D. Hirschman**, "Impact of Annealing on Contact Formation and Stability of IGZO TFTs," ECS Trans. 61 (4) 405-417 (2014) / DOI: 1149/06104.0405ecst

Annealing processes were investigated on Indium-Gallium-Zinc-Oxide (IGZO) thin-film transistors (TFTs). Molybdenum and aluminum were used as contact metals which defined the working source/drain electrodes. Annealing was performed either pre-metal or post-metal deposition, in various gas ambients including air, oxygen, nitrogen, forming gas (5% H_2 in N_2) and vacuum. Pre-metal annealing in air ambient resulted in similar I-V characteristics on Mo-contact and Al-contact devices. A post-metal anneal for Mo-contact devices resulted in higher on-state current and steeper subthreshold slope, whereas the Al-contact devices experienced severe degradation suggesting the formation of an AlO_X interface layer. A post-metal anneal at 400 °C in N_2 followed by an air ambient ramp-down yielded Mo-contact devices with *SS* ~ 200 mV/dec, channel mobility μ_{sat} ~ 8.5 cm^2/V·s, and improved stability over other anneal conditions.

5. T. Mudgal, C. Reepmeyer, R. G. Manley, D. Cormier and **K.D. Hirschman**, "Crystallization of Amorphous Silicon and Dopant Activation using Xenon Flash-Lamp Annealing (FLA)," MRS Proceedings, 1666 (2014) / DOI: http://dx.doi.org/10.1557/opl.2014.722

Flash-lamp annealing (FLA) has been investigated for the crystallization of a 60 nm amorphous silicon (a-Si) layer deposited by PECVD on display glass. Input factors to the FLA system included lamp intensity and pulse duration. Conditions required for crystallization included use of a 100 nm SiO_2 capping layer, and substrate heating resulting in a surface temperature ~ 460 °C. An irradiance threshold of ~ 20 kW/cm^2 was established, with successful crystallization achieved at a radiant exposure of 5 J/cm^2, as verified using variable angle spectroscopic ellipsometry (VASE) and Raman spectroscopy. Nickel-enhanced crystallization (NEC) using FLA was also investigated, with results suggesting an increase in crystalline volume. Different combinations of furnace annealing and FLA were studied for crystallization and activation of samples implanted with boron and phosphorus. Boron activation demonstrated a favorable response to FLA, achieving a resistivity ρ < 0.01 Ω•cm. Phosphorus activation by FLA resulted in a **resistivity ρ ~ 0.03 Ω•cm.**

IX. b. Semiconductor Devices: Santosh Kurinec

Funded by:
NSF Silicon Solar Consortium
National Science Foundation
Department of Energy funding to Intrinsiq

1. Florent K., Marshall A., M. A. Jackson, **S. Kurinec,** "Silicon Solar Consortium Towards copper metallization: investigate diffusion barrier for copper front metallization of silicon solar cells" (SiSoC) Meeting, September 2014, Atlanta, GA

A turnkey base line process has been developed to fabricate solar cells with SiO_2/Si_3N_4 as antireflection coating (ARC) and nickel silicide as Cu barrier/contact adhesion layer. Copper diffusion in silicon nitride has been investigated in order to understand the diffusion extent. TEM and EELS analysis indicate that silicon nitride is relatively resilient to copper diffusion. Cu/SiN/Si MOS capacitors were fabricated and bias temperature stress (BTS) tests using capacitance-voltage analysis were performed. Copper printing has been attempted and the results are encouraging as fine lines can be realized on ARC coated silicon.

2. K. Florent, D. MacMahon, A. Brothers and S. Kurinec "Electron Energy-Loss Spectroscopy (EELS) analysis on MoS_2 layers transferred on silicon" , Frontiers of Characterization & Metrology for Nanoelectronics, Dresden, Germany, April 2015.

Layered two-dimensional (2D) materials that can be mechanically exfoliated into single monolayers have great potential for novel information processing such as spin-based and valley-based electronics. With the advancement of microscopic and analytical techniques, significant insight knowledge has been obtained on the structure and properties of 2D materials. In this paper, the authors have carried out high resolution TEM and electron energy loss spectroscopy (EELS) to investigate MoS_2 layers interface with silicon dioxide. The results show a conformable coverage of MoS_2 on SiO_2 with interfacial reaction between MoS_2 and SiO_2.

3. S. Kurinec, C.Y. Jen, G.Tulsyan, C. Richer "Terahertz time-domain spectroscopy for characterization of doping profiles in semiconductors" Frontiers of Characterization & Metrology for Nanoelectronics, Dresden, Germany, April 2015.

Rapid progress in ultrafast fiber laser technology has enabled the emergence of several robust commercial terahertz metrology systems suitable for use in a manufacturing environment. Terahertz time-domain spectroscopy (THz-TDS) can accurately and rapidly measure the attenuation and phase delay for every frequency in the pulse bandwidth of the terahertz pulses generated and detected (by taking the Fourier transform). Here, we have extended the use of THz to monitor continuously varying depth profiles . Phosphorus doped profiles in p type silicon wafers have been investigated to reconstruct doping profiles from terahertz transmission using THz-TDS. The results demonstrate the use of this technique for rapid, non-destructive determination of diffusion profiles with a potential for in situ profile monitoring.

IX. c. Semiconductor Devices: Sean Rommel

1. P.M. Thomas, M.J. Filmer, A. Gaur, S.L. Rommel, K. Bhatnagar, and R. Droopad, "Performance evaluation of broken gap Esaki tunnel diodes on Si and GaSb substrates," Electronics Letters, vol. 52, pp. 73-75 (2016). DOI: doi:10.1049/el.2015.2290

   In-InAs/p-GaSb Esaki diodes with 3 nm GaSb i-layers are fabricated on Si and GaSb substrates. The on Si sample devices exhibit lower peak to valley ratios and peak current density than their on GaSb counterparts at 3.27 against 4.45 and 119 against 336 kA/cm2, respectively. The findings are similar to other reports of integrating III–V Esaki diodes onto Si.

2. K. Bhatnagar, M.P. Caro, J.S. Rojas-Ramirez, R. Droopad, P.M. Thomas, A. Gaur, M.J. Filmer, and S. L. Rommel, "Integration of Broken-Gap Heterojunction InAs/GaSb Esaki Tunnel Diodes on Silicon," J. Vacuum Science and Technology B, vol. 33, pp. 062203-1 - 062203-7 (2015).DOI: doi:10.1116/1.4935885

   This study entails a comparison of the broken-gap InAs/GaSb heterojunction system on two different substrates, including Si and native GaSb as a control. Through the use of different integration schemes such as AlSb and SrTiO3 buffer layers, GaSb was grown on miscut Si substrates using solid-source molecular beam epitaxy. The InAs/GaSb pþ-i-nþ heterostructures were grown on the GaSb/Si virtual substrates and compared in terms of their surface morphology and crystalline quality. Esaki tunnel diodes were fabricated, and their performance compared across the different integration platforms. The control sample shows the best peak current density of 336 kA/cm2 and a conductance slope of 274 mV/decade compared to the broken-gap junction on SrTiO3/Si and AlSb/Si virtual substrates. These results show the possibility of integrating the InAs/GaSb system in ultralow power tunnel field-effect transistors logic applications with the cost-effectiveness and maturity of the silicon technology.

3. Paul Thomas, Matthew Filmer, Abhinav Gaur, David J. Pawlik, Brian Romanczyk, Enri Marini, Sean L. Rommel, Kausik Majumdar, Wei-Yip Loh, Man Hoi Wong, Chris Hobbs, Kunal Bhatnagar, Rocio Contreras-Guerrero, and Ravi Droopad, "Performance Evaluation of In0.53Ga0.47As Esaki Tunnel Diodes on Silicon and InP Substrates", IEEE Transactions on Electron Devices, vol. 62, pp. 2450-2456, (2015). DOI: doi:10.1109/TED.2015.2445731

   In0.53Ga0.47As Esaki tunnel diodes grown by molecular beam epitaxy on an Si substrate via a graded buffer and control In0.53Ga0.47As Esaki tunnel diodes grown on an InP substrate are compared in this paper. Statistics are used as a tool to show peak-to-valley ratio for the III–V on Si sample and the control that perform similarly below 8.6 × 10−10 cm2. The existence of a critical device area suggests the potential to utilize III–V on Si for other deeply scaled tunnel devices.

4. Paul Thomas, Matthew Filmer, Abhinav Gaur, David J. Pawlik, Brian Romanczyk, Enri Marini, Sean L. Rommel, Kausik Majumdar, Wei-Yip Loh, Man Hoi Wong, Chris Hobbs, Kunal Bhatnagar, Rocio Contreras-Guerrero, and Ravi Droopad, "Performance Evaluation of In0.53Ga0.47As Esaki Tunnel Diodes on Silicon and InP Substrates", IEEE Transactions on Electron Devices, vol. 62, pp. 2450-2456, (2015). http://dx.doi.org/doi:10.1109/TED.2015.2445731

In0.53Ga0.47As Esaki tunnel diodes grown by molecular beam epitaxy on an Si substrate via a graded buffer and control In0.53Ga0.47As Esaki tunnel diodes grown on an InP substrate are compared in this paper. Statistics are used as a tool to show peak-to-valley ratio for the III–V on Si sample and the control that perform similarly below 8x10-10 cm-2 . The existence of a critical device area suggests the potential to utilize III–V on Si for other deeply scaled tunnel devices.

5. A. Gaur, M. J. Filmer, P. M. Thomas, **S. L. Rommel**, K. Bhatnagar and Ravi Droopad, "Fabrication and characterization of sub-micron In0.53Ga0.47As p-i-n diodes," *Solid-State Electronics*, *vol. 111*, pp. 234-237, (2015). http://dx.doi.org/doi:10.1016/j.sse.2015.03.016

   The impact of scaling on off-state current of p-i-n diodes is studied. A sub-micron p-i-n diode exhibits a dominating surface component of leakage current. Variation in i-layer thickness has an impact on bulk leakage. Bulk leakage scales with cross-sectional area of the diode and surface leakage has been controlled using surface treatments to give ultra low leakage currents of 210 fA for a device of cross sectional area of 0.44 μ m2. Devices of 100 nm i-layer thickness show an average bulk and surface current densities of 100 mA/cm2 and 150 fA/ μ m, respectively.

6. A. Gaur, I. Manwaring, M. J. Filmer, P. M. Thomas, **S. L. Rommel**, K. Bhatnagar and Ravi Droopad, "Surface treatments to reduce leakage current in In0.53Ga0.47As p-i-n diodes," *Journal of Vacuum Science and Technology B*, **vol. 33**, pp. 021210-01 - 021210-04, (2015). DOI: 10.1116/1.4914403

   The impact of mesa surface conditions on the dark current of a homojunction In0.53Ga0.47 As p-i-n diode has been investigated. Three treatments were performed on mesa structures with a 100 nm i-layer—sidewall exposure to O2 plasma, sulfide treatment, and divinylsiloxane-bis-benzocyclobutene (BCB) passivation that resulted in perimeter normalized current, J1, of 0.01A/cm, 0.35lA/cm, and 35 nA/cm, respectively. This study spanned several days and it was shown that sulfide layer, unless properly capped, deteriorates over time whereas the BCB passivation properly encapsulates the mesa and does not degrade for longer periods of time.

7. K Majumdar, P. Thomas, W. Loh, P. Hung, K. Matthews, D. Pawlik, B. Romanczyk, M. Filmer, A. Gaur, R. Droopad, **S.L. Rommel**, C. Hobbs, and P.D. Kirsch, "Mapping Defect Density in MBE Grown In0.53Ga0.47As Epitaxial Layers on Si Substrate Using Esaki Diode Valley Characteristics," *IEEE Transactions on Electron Devices*, **vol. 61**, pp. 2049-2055, (20 14). DOI:10.1109/TED.2014.2318597

   Growing good quality III-V epitaxial layers on Si substrate is of utmost importance to produce next generation high-performance devices in a cost effective way. In this paper, using physical analysis and electrical measurements of Esaki diodes, fabricated using molecular beam epitaxy grown In0.53Ga0.47 layers on Si substrate, we show that the valley current density is strongly correlated with the underlying epi defect density. Such a strong correlation indicates that the valley characteristics can be used to monitor the epi quality. A model is proposed to explain the experimental observations and is validated using multiple temperature diode I-V data. An excess defect density is introduced within the device using electrical and mechanical stress, both of which are found to have a direct impact on the valley current with a negligible change in the peak current characteristics, qualitatively supporting the model predictions.

X. a. Signal and Image Processing: Sohail Dianat

1. S. Zhu, **S. Dianat**, and L.K. Mestha, "End-to-end System of License Plate Localization and Recognition", J. Electron. Imaging, Vol. 24, Issue 2, March 2015.

   Abstract. An end-to-end license plate recognition system is proposed. It is composed of preprocessing, detection, segmentation, and character recognition to find and recognize plates from camera-based still images. The system utilizes connected component (CC) properties to quickly extract the license plate region. A two-stage CC filtering is utilized to address both shape and spatial relationship information to produce high precision and to recall values for detection. Floating peak and valleys of projection profiles are used to cut the license plates into individual characters. A turning function-based method is proposed to quickly and accurately recognize each character. It is further accelerated using curvature histogram-based support vector machine. The *INFTY* dataset is used to train the recognition system, and MediaLab license plate dataset is used for testing. The proposed system achieved 89.45% F-measure for detection and 87.33% accuracy for overall recognition rate which is comparable to current state-of-the-art systems

2. H. Peng, and **S. A. Dianat**, **"**Multispectral Image Denoising with Optimized Vector Bilateral Filter", Accepted for publication, IEEE Transactions on Image Processing. Vol.23, Issue: 1, pp. 264-273, January 2014.

   Abstract. Vector bilateral filtering has been shown to provide good tradeoff between noise removal and edge degradation when applied to multispectral/hyperspectral image denoising. It has also been demonstrated to provide dynamic range enhancement of bands that have impaired signal to noise ratios (SNRs). Typical vector bilateral filtering described in the literature does not use parameters satisfying optimality criteria. We introduce an approach for selection of the parameters of a vector bilateral filter through an optimization procedure rather than by ad hoc means. The approach is based on posing the filtering problem as one of nonlinear estimation and minimization of the Stein's unbiased risk estimate of this nonlinear estimator. Along the way, we provide a plausibility argument through an analytical example as to why vector bilateral filtering outperforms bandwise 2D bilateral filtering in enhancing SNR. Experimental results show that the optimized vector bilateral filter provides improved denoising performance on multispectral images when compared with several other approaches.

X. b. Signal and Image Processing: Sildomar Monteiro

Funded by: Amazon web services (AWS)

1. R. J. Murphy, S. Schneider, and **S. T. Monteiro**, "Consistency of measurements of wavelength position from hyperspectral imagery: Use of the ferric iron crystal field absorption at 900 nm as an indicator of mineralogy," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, pp. 2843–2857, 2014.

   Several environmental and sensor effects make the determination of the wavelength position of absorption features in the visible near infrared (VNIR) (400-1200 nm) from hyperspectral imagery more difficult than from nonimaging spectrometers. To evaluate this, we focus on the ferric iron crystal field absorption, located at about 900 nm (F900), because it is impacted by both environmental and sensor effects. The wavelength position of F900, determined from laboratory imagery, is also evaluated as an indicator of the proportion of goethite in mixtures of crushed rock. Results are compared with those from a high-resolution field spectrometer. Images describing the wavelength position of F900 showed large amounts of spatial variability and contained an artifact-a consistent shift in the wavelength position of F900 to longer wavelengths. These effects were greatly reduced or removed when wavelength position was determined from a polynomial fit to the data, enabling wavelength position to be used to map hematite and goethite in samples of ore and on a vertical surface (a mine face). The wavelength position of F900 from a polynomial fit was strongly positively correlated with the proportion of goethite (R2=0.97). Taken together, these findings indicate that the wavelength position of absorption features from VNIR imagery should be determined from a polynomial (or equivalent) fit to the original data and not from the original data themselves.

2. R. J. Murphy, S. Schneider, and **S. T. Monteiro**, "Mapping layers of clay in a vertical geological surface using hyperspectral imagery: Variability in parameters of swir absorption features under different conditions of illumination," *Remote Sensing*, vol. 6, no. 9, pp. 9104–9129, 2014.

   Hyperspectral imagery of a vertical mine face acquired from a field-based platform is used to evaluate the effects of different conditions of illumination on absorption feature parameters wavelength position, depth and width. Imagery was acquired at different times of the day under direct solar illumination and under diffuse illumination imposed by cloud cover. Imagery acquired under direct solar illumination did not show large amounts of variability in any absorption feature parameter; however, imagery acquired under cloud caused changes in absorption feature parameters. These included the introduction of a spurious absorption feature at wavelengths > 2250 nm and a shifting of the wavelength position of specific clay absorption features to longer or shorter wavelengths. Absorption feature depth increased. The spatial patterns of clay absorption in imagery acquired under similar conditions of direct illumination were preserved but not in imagery acquired under cloud. Kaolinite, ferruginous smectite and nontronite were identified and mapped on the mine face. Results were validated by comparing them with predictions from x-ray diffraction and laboratory hyperspectral imagery of samples acquired from the mine face. These results have implications for the collection of hyperspectral data from field-based platforms.

3. Y. Liu, **S. T. Monteiro**, and E. Saber, "An approach for combining airborne LiDAR and high-resolution aerial color imagery using Gaussian processes," 2015, p. 96430Z.

   Changes in vegetation cover, building construction, road network and traffic conditions caused by urban expansion affect the human habitat as well as the natural environment in rapidly developing cities. It is crucial to assess these changes and respond accordingly by identifying man-made and natural structures with accurate classification algorithms. With the increase in use of multi-sensor remote sensing systems, researchers are able to obtain a more complete description of the scene of interest. By utilizing multi-sensor data, the accuracy of classification algorithms can be improved. In this paper, we propose a method for combining 3D LiDAR point clouds and high-resolution color images to classify urban areas using Gaussian processes (GP). GP classification is a powerful non-parametric classification method that yields probabilistic classification results. n this paper, we attempt to identify man-made and natural objects in urban areas including buildings, roads, trees, grass, water and vehicles. LiDAR features are derived from the 3D point clouds and the spatial and color features are extracted from RGB images. For classification, we use the Laplacian approximation for GP binary classification on the new combined feature space. The multiclass classification has been implemented by using one-vs-all binary classification strategy. The result of applying support vector machines (SVMs) and logistic regression (LR) classifier is also provided for comparison. Our experiments show a clear improvement of classification results by using the two sensors combined instead of each sensor separately. Also we found the advantage of applying GP approach to handle the uncertainty in classification result without compromising accuracy compared to SVM, which is considered as the state-of-the-art classification method.

4. Y. Hu, N. D. Cahill, **S. T. Monteiro**, E. Saber, and D. W. Messinger, "Low-dimensional representations of hyperspectral data for use in CRF-based classification," 2015, p. 96430L.

   Probabilistic graphical models have strong potential for use in hyperspectral image classification. One important class of probabilisitic graphical models is the Conditional Random Field (CRF), which has distinct advantages over traditional Markov Random Fields (MRF), including: no independence assumption is made over the observation, and local and pairwise potential features can be defined with flexibility. Conventional methods for hyperspectral image classification utilize all spectral bands and assign the corresponding raw intensity values into the feature functions in CRFs. These methods, however, require significant computational efforts and yield an ambiguous summary from the data. To mitigate these problems, we propose a novel processing method for hyperspectral image classification by incorporating a lower dimensional representation into the CRFs. In this paper, we use representations based on three types of graph-based dimensionality reduction algorithms: Laplacian Eigemaps (LE), Spatial-Spectral Schroedinger Eigenmaps (SSSE), and Local Linear Embedding (LLE), and we investigate the impact of choice of representation on the subsequent CRF-based classifications.

5. Y. Hu, E. Saber, **S. T. Monteiro**, N. D. Cahill, and D. W. Messinger, "Classification of hyperspectral images based on conditional random fields," in *IS&T/SPIE Electronic Imaging (EI)*, (San Francisco, CA), pp. 940510-940510-8, Feb. 2015.

   A significant increase in the availability of high resolution hyperspectral images has led to the need for developing pertinent techniques in image analysis, such as classification. Hyperspectral images that are correlated spatially and spectrally provide ample information across the bands to benefit this purpose. Conditional Random Fields (CRFs) are discriminative models that carry several advantages over conventional techniques: no requirement of the independence assumption for observations, flexibility in defining local and pairwise potentials, and an independence between the modules of feature selection and parameter leaning. In this paper we present a framework for classifying remotely sensed imagery based on CRFs. We apply a Support Vector Machine (SVM) classifier to raw remotely sensed imagery data in order to generate more meaningful feature potentials to the CRFs model. This approach produces promising results when tested with publicly available AVIRIS Indian Pine imagery.