Abstract Booklet

Engineering Graduate Symposium 2012

Friday, November 2, 2012
# Table of Contents

Message from the Chairs 5  
Committee and Volunteers 6  
Sponsors 9  
Abstracts 17  
  
Automotive Engineering 199  
Civil and Environmental Engineering 277  
Computer Science and Software Design 39  
Design and Manufacturing 47  
Earth Science and Remote Sensing 55  
Energy 69  
Engineering in Biological Systems 77  
Engineering in Medicine 93  
Fluid Dynamics, Thermodynamics, Heat Transfer and Combustion 105  
IOE and Financial Engineering 117  
Materials and Chemical Technology 129  
Micro-Electromechanical Systems 147  
Microfluidics 1599  
Nanotechnology 165  
Naval Architecture and Marine Engineering 183  
Nuclear Science, Energy, and Engineering 191  
Power and Control 211  
RF and Applied Electromagnetics 219  
Signal Processing and Computer Vision 227  
Solid State Materials and Physics 251  
Space Research and Aerospace Engineering 263  
Systems Engineering and Communications 273  
Richard and Eleanor Towner Award 285
From the Chairs

On behalf of the planning committee and the College of Engineering, we would like to welcome you to the 7th annual Engineering Graduate Symposium (EGS ’12). The EGS ’12 will be held on Friday, November 2, 2012, throughout the College of Engineering. This is an exciting gathering of engineering graduate students, prospective students, faculty, entrepreneurs, and industry sponsors.

This year’s Engineering Graduate Symposium is focused on the theme “Collaboration in Engineering” and is organized to boost the spirit of collaboration, innovation, and communication among graduate students in an interdisciplinary environment. The EGS ’12 will consist of keynote lectures, invited talks from industry, research poster sessions and an awards ceremony. The Symposium will enable graduate students to share their research and accomplishments as well as review the research currently being conducted by their peers. In addition to the rich technical program, the Symposium hosts special sessions and tours for prospective graduate students invited from top schools nationwide, introducing them to the broad research portfolio of the College of Engineering.

We cordially invite you to participate in this exciting event as organizers, presenters, prospective students, and/or sponsors. Please do not hesitate to email us at SymposiumInfo@umich.edu if you have any questions, comments, or would like to get involved.

We look forward to meeting you and welcoming you on November 2, 2012.

Best regards,
Sahar Rahmani and Adam Lobbestael
Symposium Co-Chairs
## Committee and Volunteers

<table>
<thead>
<tr>
<th>Name</th>
<th>Department</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike Nazareth</td>
<td></td>
<td>Director for Graduate Recruitment</td>
</tr>
<tr>
<td>Andria Rose</td>
<td></td>
<td>Coordinator for Graduate Education Programs</td>
</tr>
<tr>
<td>Shira Washington</td>
<td></td>
<td>Coordinator for Graduate Education Programs</td>
</tr>
<tr>
<td>Adam Lobbestael</td>
<td>CEE</td>
<td>EGS Planning Committee Chair</td>
</tr>
<tr>
<td>Sahar Rahmani</td>
<td>BME</td>
<td>EGS Planning Committee Chair</td>
</tr>
<tr>
<td>Marina Acevedo</td>
<td>CEE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Michael Allison</td>
<td>EE:Sys</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Mostafa Bedewy</td>
<td>ME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Barry Belmont</td>
<td>BME</td>
<td>EGS Editor</td>
</tr>
<tr>
<td>Yu-Chih Chen</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Kenneth Cheng</td>
<td>MS&amp;E</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Liz Cloos</td>
<td>EE</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Gerardo Cruz</td>
<td>Aero</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Jacob Davidson</td>
<td>Aero</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Mathieu Davis</td>
<td>ME</td>
<td>EGS Photographer &amp; Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Gina DiBraccio</td>
<td>AOSS</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Name</td>
<td>Department</td>
<td>Role</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Jennifer Dolan</td>
<td>NERS</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Alex Emly</td>
<td>MS&amp;E</td>
<td>EGS Sponsor Recruiter</td>
</tr>
<tr>
<td>Gurkan Gok</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Ko Jen Hsia</td>
<td>EE:Sys</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>I-Ning Hu</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Jacob Jordahl</td>
<td>BME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Alexis Kaplan</td>
<td>NERS</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Abhishek Kumar</td>
<td>Aero</td>
<td>EGS Awards Dinner Chair &amp; Logistics Coordinator</td>
</tr>
<tr>
<td>Yu-Ju Lin</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Joyce Loh</td>
<td>MS&amp;E</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Thomas McKenney</td>
<td>NAME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Adam Mendrela</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Asish Misra</td>
<td>BME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Ibrahim Mohedas</td>
<td>ME</td>
<td>EGS Session Chair &amp; Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Gopal Nataraj</td>
<td>EE:Sys</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Hai Nguyen</td>
<td>ME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Arun Padakandla</td>
<td>EE:Sys</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Brandon Patterson</td>
<td>ME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Bruce Pierson</td>
<td>NERS</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Sara Rimer</td>
<td>CEE</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Astin Ross</td>
<td>BME</td>
<td>Publicity Coordinator</td>
</tr>
<tr>
<td>Name</td>
<td>Department</td>
<td>Position</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>Cori Roth</td>
<td>ChE</td>
<td>Prospective Student Activity Committee</td>
</tr>
<tr>
<td>Onajite Shemi</td>
<td>ChE</td>
<td>EGS Editor</td>
</tr>
<tr>
<td>Zohar Strinka</td>
<td>IOE</td>
<td>EGS Sponsor Recruiter</td>
</tr>
<tr>
<td>Catherine Walker</td>
<td>AOSS</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Jihyeon Yeom</td>
<td>BME</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Denny Yu</td>
<td>IOE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Eric Kai-Hsiang Yu</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Cheng Zhang</td>
<td>EE</td>
<td>EGS Session Chair</td>
</tr>
<tr>
<td>Yiting Zhang</td>
<td>EE</td>
<td>Prospective Student Activity Committee</td>
</tr>
</tbody>
</table>
Sponsors
Learn About Technical Consulting
Ph.D. Information Session

Date: Friday, November 2nd
Time: 4:00–5:00pm
Location: 1200 EECS

Things break, ignite, corrode, arc, wreck, degrade, and can otherwise get mangled, damaged, or just simply not work correctly for any number of reasons. Students graduating with doctorates in engineering and science possess valuable expertise that is highly sought after by clients around the world. Exponent gives you the opportunity to work alongside hundreds of top notch professionals to help clients solve their most challenging and high exposure technical problems.

This presentation will help students understand the role of the technical consultant and the career opportunities available to them at Exponent. Case studies describing examples of engineering failure analysis, product design, and accident investigation will be discussed.

Visit us at the Grad Symposium on Nov. 2nd!
Siobhan Costello, Recruiter • scostello@exponent.com
ONE BIG IDEA.
UNLIMITED POSSIBILITIES.

As the world leader in next-gen mobile technologies, Qualcomm is focused on one big idea — accelerating mobility around the globe.

Learn more about career opportunities at Qualcomm, visit:
qualcomm.com/careers

© 2011 Qualcomm Incorporated. All Rights Reserved.
World-changing technologies.
Life-changing careers.

Imagine your career here.

Sandia is a top science and engineering laboratory for national security and technology innovation. Here you’ll find rewarding career opportunities for the Bachelor’s, Master’s, and Ph.D. levels in:

- Electrical Engineering
- Mechanical Engineering
- Computer Science
- Computer Engineering
- Systems Engineering
- Chemistry
- Physics
- Materials Science
- Business Applications
- Mathematics, Information Systems

We also offer exciting internship, co-op, post-doctoral, and graduate fellowship programs.

www.sandia.gov/careers

Stop by our booth at the Engineering Grad Symposium on November 2, 2012 from 10am – 3pm! We are located at the connector between the Duderstadt and Pierpont Commons.

We are excited to meet graduate students at all stages of their academic career.

If you are expected to graduate soon, please bring your resume.
Ann Arbor Area FedEx Offices

24-Hour Location 2800 S State St, Ann Arbor, MI 48104
Phone: 734.665.2400  E-mail: usa0842@fedex.com

505 East Liberty Street, Ann Arbor, MI 48104
Phone: 734.761.4539  E-mail: usa0411@fedex.com

2609 Plymouth Rd, Ann Arbor, MI 48105
Phone: 734.996.0050  E-mail: usa0465@fedex.com

3354 Washtenaw Rd, Ann Arbor, MI 48104
Phone: 734.975.0496  E-mail: usa1781@fedex.com
Soar Technology, Inc.

Soar Technology, Inc. (SoarTech) is a leader in the research and development of knowledge-rich intelligent systems that automate complex tasks, simplify human-system interaction, and model human behavior for military and civilian applications. We apply this technology in three main business areas:

**Intelligent Training**

SoarTech is a world leader in the development of intelligent behavior models to support simulation-based and immersive training applications. Our intelligent behavior models cover the full spectrum from socially and culturally focused for SSTR training to tactically focused for MCO training. SoarTech also develops serious games that integrate our advanced behavior models and our recent research in pedagogic experience tailoring and intelligent tutoring.

**Autonomous Platforms**

The same technologies that have enabled SoarTech to bring human level intelligence and natural, multi-modal interfaces to simulation systems are now being used to build intelligent, autonomous, and collaborative robotic systems. Robotic intelligence frees humans from being “tethered” to a robot – and makes the robot a true “teammate” instead of a piece of equipment.

**Data to Decisions**

The most complex thing humans do is decide. A single decision requires that you accumulate evidence from diverse sensory inputs, associate past memories, integrate knowledge from repositories, collaborate, address uncertainty, learn, convert raw information to symbols, reason and, finally, decide. Deciding is a natural part of cognition, and we do it easily and naturally. At SoarTech, we build software to mimic this process with incredible possibilities every day.

Soar Technology has openings for Principal Investigators, Software Engineers, and Artificial Intelligence Engineers. For more information visit our website at [www.soartech.com](http://www.soartech.com).
Abstracts
Automotive Engineering

Session Chair: Ibrahim Mohedas
A simplified skid-steering model for torque and power analysis of tracked small unmanned ground vehicles
Tianyou Guo¹, Huei Peng¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

The ability to predict the torque and power consumption of a tracked robot, a.k.a., small unmanned ground vehicle (SUGV) is critical for its design. This is because accurate torque and power consumption prediction enables motion planning that does not exceed the torque and power limitations of the propulsion system or the terrain. Due to the fact that skid steering can consume a large percentage of the propulsion power of the tracked SUGVs, it must be included in any accurate power analysis. Modeling of skid steering of tracks is difficult on soft soils because of the track-soil interaction and the distributed nature of shear stress along the contacting area. This study begins with a general theory of skid steering track-soil interaction in steady state. A fast yet accurate 2-D simplified model is then developed, which is solved with pre-calculated skid steering resistance coefficient maps. Subsequently a quadratic equation for internal power consumption is deduced experimentally. The simplified model is then verified using the experimental data obtained from an iRobot Packbot driving on dry sand. Moreover this study includes a comparison simulation for power and torque consumption, efficiency and mobility between tracked and wheeled SUGV on various terrain.

This work was funded by the Automotive Research Center (ARC), a U.S. Army center of excellence in modeling and simulation of ground vehicles at the University of Michigan.
Your car is likely to be spammed
Kyusuk Han¹, Swapna Divya Potluri¹, Kang G. Shin¹

¹Department of Electrical Engineering & Computer Science, University of Michigan, Ann Arbor, MI

Smart phones and tablets have been integrated with every aspect of our lives including computers, home devices and the cloud. We are no longer restricted to buildings, we can now be connected in our cars as well. The Recent advances in vehicular technology have paved way to a new era of connectivity. Vehicle Manufacturers already deploy various technologies for driving assistance, anti-theft, and infotainment. They are now coming up with ways to interface mobile devices and giving the consumer the power of functionality control akin to smart phones. However, there is huge concern that such intelligence will also bring severe security threats to the vehicular environment due to the design nature of the vehicular technologies. Since the architecture of in-vehicle communication was designed only considering the isolated environment, security of the in-vehicle network was rather out of focus. In fact, several studies already showed that the controller area network is easy to be attacked just by connecting to cheap commercial devices. Many researchers also argue that a strong security model is required for implementing the connectivity into the vehicle. Therefore, in this session, we address privacy and authentication issues in the connected vehicle. We will show the possible attack cases and present how to prevent them.
Vehicle dynamic motion control to mitigate secondary collisions
Byung-joo Kim¹, Huei Peng¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

In vehicle to vehicle crashes, even a light collision between vehicles can lead to devastating consequences if the driver does not make a proper judgment after an unexpected impact. Electronic Stability Control (ESC) was shown to have positive effects on reducing single vehicle crashes, however, its effect on reducing the secondary crash has not been fully developed, especially for first events that are strong enough that typical drivers could not react properly to avoid subsequent crashes. The objective of this study is to develop a post-impact vehicle stability control system that regulates both heading angle and lateral deviation from the original driving path, so that the severity of possible subsequent (secondary) crashes can be reduced. To characterize the vehicle motion after a crash event, an impact force estimation method and a vehicle motion prediction scheme are proposed. If the predicted unmitigated final heading angle is undesirable, and/or a large lateral deviation is expected, then proper differential braking and possibly steering action will be taken to drive the vehicle motion to a desired final state. Simulations and analysis results of the proposed state estimation and prediction algorithm will be evaluated, followed by the presentation on the proposed control algorithm.
High fidelity flamelet combustion model for simulation of advanced internal combustion engines

Pinaki Pal¹, Hong G. Im¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

A novel flamelet-based turbulent spray combustion model coupled with a multi-dimensional computational fluid dynamic (CFD) code was employed to investigate the effects of direct injection on homogeneous charge compression ignition (HCCI) engine operation at low load. The model is based on the flamelet concept which assumes that complex chemical reaction processes occur within a narrow region in physical length scale, and hence can be described in a reduced dimensional space. The flamelet model framework allows a cost-effective and accurate description of full turbulence-chemistry coupling. The model also fully incorporates the interaction between spray evaporation and gas-phase combustion. A wide range of Start-of-Injection timings were numerically examined at a low load HCCI operating condition. For earlier fuel injection, the in-cylinder mixture was homogeneous and overall lean, leading to low bulk gas temperatures and incomplete CO-CO₂ conversion. For retarded injections, the cylinder charge had locally rich mixture, such that stable ignition and combustion was maintained for complete CO-CO₂ reaction, leading to higher combustion efficiency. However, high NOₓ emissions imposed a practical constraint on the extent to which SOI could be delayed. Flamelet model predictions of pressure traces, combustion efficiency, and CO and NOₓ emissions were found to be in very good agreement with experimental results. In addition, comparison with the predictions of a multi-zone (MZ) combustion model showed that the flamelet model performs much better, especially at highly stratified conditions, as it accounts for the effect of subgrid scale mixing effects on combustion, which are not incorporated in the MZ model.

This work was funded by Department of Energy (DOE).
Modeling of wheel-soil interaction over rough terrain using the discrete element method

William Smith¹, Huei Peng¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

Small unmanned ground vehicles often operate in unimproved, off-road terrain. Given their small size, ground surface roughness may have a significant impact on vehicle performance and mobility. To assess these impacts, a numerical study was conducted using the discrete element method (DEM) to simulate the interaction between a small rigid wheel and lunar regolith simulant. In order to validate the DEM technique, steady-state locomotion and wheel-digging tests were simulated and compared to experimental results from the literature. Percent error was generally less than 20 percent, with good qualitative agreement. Rough terrain was modeled using 20 sinusoidal profiles with varying frequency and amplitude. The influence of the rough terrain may have been limited by the low longitudinal velocity of the wheel and the softness of the soil, which did not produce appreciable vertical vibration. Nevertheless, wheel mobility and efficiency were decreased compared to flat, level operation. At low slip ratios the average drawbar pull decreased as much as 15%, while torque increased as much as 35%. The frequency of the sinusoidal surface profile helped create oscillations in drawbar pull and driving torque with significantly greater maximum and minimum values compared to flat terrain. These oscillations may increase the likelihood of vehicle immobilization, while decreasing efficiency.

This work was funded, in part, by the Science, Mathematics & Research for Transformation (SMART) Scholarship.
Prius+ and Volt–: configuration analysis of power-split hybrid vehicles with a single planetary gear
Xiaowu Zhang¹, Chiao-Ting Li¹, Huei Peng¹, Jing Sun²

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
²Department of Naval Architecture, University of Michigan, Ann Arbor, MI

The majority of the hybrid electric vehicles (HEVs) available on the market are power-split hybrid vehicles with a single planetary gear (PG), including the popular Toyota Prius and Chevy Volt. Although both vehicles use a single PG, they have different configurations with different number of operating modes. The Prius has no clutch and has a single operating mode, whereas the Chevy Volt uses three clutches and has four modes. The goal of this paper is to present a thorough analysis on all possible configurations of power-split hybrid powertrain using a single planetary gear. The analysis includes: 1) search for all possible ways to connect powertrain elements to the PG, 2) identify all potential locations for clutch installations around the PG and examine the feasibility of additional operating modes introduced by the clutch installation; and, 3) optimize the fuel economy for performance comparison. The proposed analysis shows that a single PG can produce 12 different configurations, and each of which can have four feasible operating modes by adding three clutches to the PG. In case studies, we focus on the two configurations that are used in the Prius and Volt in order to find the impact of the additional (or removal of) clutches and modes on their fuel economy performance. Our results show that adding one clutch to the Prius transmission (which is named ‘Prius+’) can significantly improve the fuel economy in urban driving, while removing two clutch from the Volt transmission (‘Volt–’) will not significantly affect the fuel economy in both urban and highway driving. This multi-mode configuration analysis can be used to systematically design future power-split HEV.

This work was funded, in part, by CERC-CVC.
Civil and Environmental Engineering

Session Chair: Marina Acevedo
Effects of workers’ social learning: focusing on absence behavior

Seungjun Ahn¹, SangHyun Lee¹, and Robert P. Steel²

¹Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI
²College of Business, University of Michigan-Dearborn, Dearborn, MI

Workers’ consistent attendance is an indispensable condition for successful construction project, but still many construction projects suffer from the productivity loss originating from workers’ absenteeism. To deal with this problem, construction managers have been mainly using formal controls (e.g., penalty) targeting those individuals who present excessive absenteeism. However, recent research papers on absenteeism have testified to the paramount role of social factors, such as social norm, on workers’ absence behavior. If how social norms emerge and play the role in controlling worker’s behavior is clear, construction managers can invest their efforts to promote favorable absence norms rather than focusing on regulations targeting individuals. Therefore, we study the system-level effect of workers’ social learning using an experimental analysis with simulations. To conduct the analysis, an agent-based model was developed to serve as a comprehensive model that incorporates mechanisms of workers’ formal and social learning. The model was constructed by using theoretical and empirical findings on absence behavior drawn from scholarly literature. Then, the constructed agent-based model was used to explore possible scenarios in organizations with simulations. With the simulation results, we demonstrate the following: (1) High social adaptation can work as a force to either increase or decrease workers’ absence rates; (2) When strong self-regulation is prevalent among workers, high social adaptation can lead to the development of a positive social norm at the jobsite; and (3) When high social adaptation reinforces formal rules, this occurrence reduces the need for additional formal controls on worker behavior. We expect the result of this work will help construction organizations understand the availability of social norms in favor of management, and ultimately use the social norm for effective labor control that meets little resistance.

This work was funded, in part, by the National Science Foundation Award (SES 1127570)
Effect of social network type on building occupant energy use

Kyle Anderson\textsuperscript{1} and SangHyun Lee\textsuperscript{1}

\textsuperscript{1}Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI

The energy demands of buildings have been shown to vary considerably due to differences in occupant energy use behavior. In buildings, occupants are subject to social pressures and influences which help moderate what is and what is not acceptable behavior, including energy use behavior. This transmission of social influence and the creation of social norms occur through social networks. Recent research has examined changes in occupant energy use behavior due to social influence through social networks, but has done so considering only one network type at a time. Therefore, this study investigates the impact of network type on occupant energy use behavior and consumption. Agent-based modeling is applied to explore the effect of network type for two separate administrative actions on reducing energy consumption: increasing social connectivity and implementing environmental champions. Results indicate that social network type is not significant in determining mean energy use change, but is when considering the time required for the system to reach equilibrium, through convergence or grouping. Additionally, based on initial distributions increasing social connectivity has undesired effects without the presence of environmental champions; however, with them, increasing social connectivity can significantly decrease the time required to realize energy savings and amplifies the reductions. These results further suggest that through administrative actions aimed at increasing social connectivity in buildings can lower variance in potential outcomes in energy use change caused by social norm diffusion.
Enhanced diffusion of chlorinated organic compounds into aquitards due to cracking

Derya Ayral¹, Margarita Otero¹, Susie Chung¹, Mark Goltz², Junqi Huang³, and Avery Demond¹

¹University of Michigan, Ann Arbor, MI  
²Air Force Institute of Technology, Wright Patterson AFB OH  
³U.S. EPA R.S. Kerr Laboratory, Ada OK

Due to the possibility that DNAPLs can act as a long-term source for a dissolved phase contaminant plume, remediation of sites contaminated with dense non-aqueous phase liquids (DNAPLs) is regarded as a very significant issue. Current models are based on the possibility of diffusion and storage of these compounds in unfractured low permeability layers. However, the impact of cracks in the soil media needs consideration as well, independent from the reason of cracking. Diffusion coefficient of trichloroethylene (TCE) through low permeability soil, representing aquitards in the field sites, was measured at steady-state, and time-lag method was used as the analytical solution. The total diffusive flux is considered to have two components: diffusion through uncracked matrix and diffusion through cracked matrix. The experimental effective diffusion coefficients were used to calculate the flux through uncracked matrix whereas bulk diffusion coefficient was used to calculate flux through the cracks. By using the experimentally-obtained diffusion coefficients and experimentally-measured crack intensity factors (the ratio of the area of cracks to the uncracked area), the total flux was estimated over extended time periods.

This work was funded by Strategic Environment Research and Develop Program (SERDP)
Improving building energy efficiency and comfort through innovative design and wireless connectivity
Michael B. Kane\textsuperscript{1,2}, Zeshi Zheng\textsuperscript{1}, Jerome P. Lynch\textsuperscript{1,2}, Geoffrey Thun \textsuperscript{3}

\textsuperscript{1}Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Taubman College of Architecture and Urban Planning, University of Michigan, Ann Arbor, MI

The energy consumed by building systems such as lighting, heating, ventilation, and air conditioning (HVAC) make up a significant portion of the nation's total energy consumption. Since much of the building stock predates modern energy efficient digital controllers, a need exists for an inexpensive and noninvasive standard for retrofitting existing residences and commercial buildings. To this end, the authors have developed the \textit{Martlet}, a new wireless controller design specifically for the needs of controlling large scale civil systems such as those found in buildings. The primary features of the \textit{Martlet} include a dual computational core for simultaneous execution of the control law and system overhead, and an extensible design permitting the wireless connectivity and control of a wide variety of sensors and actuators. In an effort to develop and assess the \textit{Martlet} outside the laboratory, the authors have signed an agreement with the University of Michigan Planet Blue Operations Teams for monitoring, modeling, and control of the Biomedical Science Research Building (BSRB). Featuring an innovative double skin façade and a complex HVAC system, the BSRB provides many opportunities for improving building performance by adopting wireless control. One exciting opportunity will take advantage of the double skin glass façade by installing automated shading and ventilation to use the suns energy to its fullest. The lessons learned deploying a network of \textit{Martlet} wireless controllers on BSRB will provide valuable insight into the nuances associated with retrofitting building systems with wireless controllers in an effort to increase energy savings and occupant comfort.

\textit{This work was funded, in part, by US Office of Naval Research (Contracts N00014-05-1-0596 and N00014-09-C0103 granted to Jerome P. Lynch), and the University of Michigan Office of the Vice President of Research.}
Vegetated marsh flow characterized using particle image velocimetry
Jenahvive Morgan¹, Aline Cotel¹, Paul Webb²

¹Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI
²School of Natural Resources and the Environment, University of Michigan, Ann Arbor, MI

The evaluation of wake flows due to aquatic vegetation is necessary to understand the response of the environment to flow through a marsh. Considering the influence of vegetation on the turbulent characteristics of the flow is important in understanding its effect on the surrounding environment and can be applied to the design and creation of artificial marsh environments for restoration projects. Vegetative environments, due to their structure, create turbulence in the flow which in turn affects the response of the native fish species, as well as contaminant and sediment transport. In an effort to model an aquatic vegetative environment, arrays of vertically aligned cylinders of diameter equal to 1/4" were set-up in staggered positions to create a variety of flow configurations in a re-circulating water tunnel. Particle Image Velocimetry (PIV) was used to determine flow characteristics at different velocities for each geometry. In particular, turbulence downstream of the cylinders was examined for different arrangements of the marsh model. The data reveal a strong relationship between the arrangement of the cylinder arrays and the wake turbulence downstream of the cylinders. These results have implications for fish responses to aquatic environment and the design of artificial wetlands.

This work was funded, in part, by National Science Foundation (#0447427)
Modeling beam-column connections at ambient and elevated temperatures using finite element analysis

Thi Thu Ha Nguyen\textsuperscript{1} and Ann E. Jeffers\textsuperscript{1}

\textsuperscript{1}Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI

Structural fire engineering has been developed in some recent decades, especially since the catastrophic collapse of World Trade Center Building 7 due to fire in 2001. Studies have been mostly carried out on individual elements such as beams, columns, and slabs; whereas there is very limited research into structural connections, partly because of the extreme high cost of those experiments and the complication in modeling process. The objective of the work is to simulate the behaviors of beam-column connections in fire scenarios with the help of ABAQUS - a commercial finite element program, focusing on steel shear connections at both ambient and elevated temperatures. The simulation process for elevated temperatures can be divided into two stages: using heat transfer analysis to obtain the temperature distribution through structural parts; and using structural analysis to obtain the fire responses, with the consideration of the change in thermal and mechanical properties of materials with respect to temperatures. In order to capture the complicated performances of structures subjected to fire, the models used high-resolution finite element analyses, taking account of the non-linearity in geometry and material. Mechanical and thermal behaviors of contacts between different parts were also included in the model. Finally, the simulation's results were validated against experimental data of steel fin plate connections in a standard fire test. Based on the high-resolution finite element simulations, this study intends to develop a macro-element model which can save much time and computational cost, but still provide appropriate results.
Development of green and durable fiber reinforced geopolymer composites for truly sustainable infrastructure applications
Motohiro Ohno

Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI

The objective of this research is to develop durable fiber reinforced geopolymer composites. Geopolymer, also known as alkali-activated aluminosilicate, is a highly green binder material and promising as an alternative construction material to Ordinary Portland Cement (OPC). However, regardless of the outstanding environmental friendliness of geopolymer, the commercial use has to date been limited to niche applications or small scale products. To make the most of the excellent material greenness of geopolymer, large-scale applications in the construction industry should be seriously considered. One of the most significant technical challenges is the inherent brittleness of geopolymer, which causes large cracking and corresponding low durability. To control the material brittleness and enhance the durability, fiber reinforcing is highly effective in geopolymer, as well as in OPC-based materials. This study firstly shows a systematic design method of fiber reinforced geopolymer composites, integrating three design techniques; Micromechanical modeling, Design of Experiment and Life Cycle Analysis. Then, a feasibility study of fiber reinforced geopolymer is done based on Micromechanical modeling, and the experimental results so far on tensile ductility, geopolymer matrix performance and fiber/matrix interface properties are shown. The ideas proposed in this study are beneficial to fulfilling the green potential of geopolymer materials, and support the development of more sustainable civil infrastructure system in the future.

This work was funded, in part, by National Science Foundation.
Recent studies show that chlorinated phenol compounds, such as some disinfection by-products and commercial sanitizers, can activate antibiotic resistant phenotypes in bacteria as well as alter the biofilm development of bacterial communities. It is a concern that conditions in point-of-use (PoU) water filters, which are effective in adsorbing many chlorinated contaminants, may serve as incubators for the development of antibiotic resistance. Experiments were conducted in this study to determine whether exposure to sorbed pentachlorophenol (PCP) during a PoU filter’s lifetime affects the abundance, antibiotic resistance, and/or the biofilm development of the filter’s microbial community. Commercial solid activated carbon block (SBAC) filters were tested in a faucet-mounted mode with tap water containing varying added concentrations of PCP (0-100 ng/L) while the effluent was monitored. Flow on-off and stagnation cycles simulated typical patterns of household drinking water filter use over the rated design life of the filter. Changes in the number of bacteria in the filter effluent were characterized in terms of heterotrophic plate counts. The resistance of indigenous bacteria shed by the filters to three antibiotics (gentamicin, tetracycline, and ciprofloxacin) was assessed by comparative plating on R2A media with and without antibiotics. The relative behaviors of these filter systems and their potential as incubators for antibiotic resistant bacteria will be discussed.

This work was funded, in part, by the National Science Foundation.
Water sustainability at a wildlife foundation in Kenya
Chelsea Ransom¹, Steven Rippberger², Alicia Ritzenthaler²

¹Department of Environmental Engineering, and School of Natural Resources and the Environment, University of Michigan, Ann Arbor, MI
²School of Natural Resources and the Environment, University of Michigan, Ann Arbor, MI

The Mpala Conservancy, located in Kenya’s semi-arid Rift Valley, faces the increasing pressure of water scarcity and the challenge of using that resource sustainably. This report provides them with recommendations on how to increase their water security by quantifying demand, assessing the availability of resources, and improving quality. Demand was measured with flow meters at 26 locations throughout the property, and daily bednight records were used to normalize demand per capita. To meet their demand, Mpala draws water from the Ewaso Nyiro River, the Miocene Aquifer, rooftop harvested rainwater, and the Nanja weirs. Assuming average rainfall, the Nanja weirs should meet their demand, but rainfall strongly influences whether or not the amount captured and stored during the rainy season will be sufficient in a drought. Demand prediction and weir volume estimate tools were developed to aid future monitoring and management. Water quality analyses were also conducted at primary sources and numerous points of use. Based on high turbidity and biological contamination, full water treatment is recommended for drinking and cooking. Pretreatment such as roughing filtration is sufficient for bathing, and if followed by slow sand filtration and disinfection, will provide potable water. Behavioral, managerial, and technical recommendations are also provided, including relying on the Nanja weirs as the primary source, and installing storage tanks and roughing filters. Mpala should also link projected demand based on expected bednights, with current storage in the weirs to plan for potential water shortages. Monitoring of water quality, availability and use should be continued.

*This work was funded, in part, by the Graham Institute of Sustainability*
Seismic response of landfills: in-situ evaluation of dynamic properties of municipal solid waste, comparison to laboratory testing, and impact on numerical analysis
A. Sahadewa¹, D. Zekkos, N. Matasovic², R. D. Woods¹, K. H. Stokoe II ³, and M. R. Tufenkjian⁴

¹Department of Civil and Environmental Eng., University of Michigan, Ann Arbor, MI
²Geosyntec Consultants, Huntington Beach, CA
³Department of Civil, Architectural & Environmental Eng., University of Texas, Austin, TX
⁴Department of Civil Eng., California State University, Los Angeles, LA

Modern Municipal Solid Waste (MSW) landfills need to withstand earthquake loading. But, case histories of performance of modern (post 90s) landfills and their seismic records in the US are very limited. Consequently, our understanding toward the response of MSW during dynamic load is still rudimentary and inadequate. The seismic response cannot be reliably assessed unless accurate and representative dynamic properties of MSW are used. Amongst the most important dynamic properties of MSW are shear wave velocity, shear modulus, and shear modulus reduction curve. As part of this research, these properties are investigated via field and laboratory testing. Field testing is performed in several landfills in Michigan, Texas, California, and Arizona. Shear wave velocity or shear modulus is evaluated in-situ using surface wave-based methodology. Mobile shaker facilities of George E. Brown, Jr Network for Earthquake Engineering Simulation (NEES) at the University of Texas at Austin provide exciting opportunity to evaluate shear modulus reduction curve of MSW in-situ for the first time. Laboratory testing is performed by using automated large-scale cyclic simple shear device. Results from field and laboratory testing will be compared to evaluate whether reconstituted MSW samples are representative of field conditions or not. The new data will be used in numerical analysis to develop recommendations for practice in landfill engineering.

This work was funded by NSF.
Multi-physical modeling and numerical simulation of thawing soil
Yao Zhang¹, Radoslaw L. Michalowski¹

¹Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI

Thawing of frozen frost-susceptible soils often causes substantial damage to infrastructure. Thaw settlement of ice-rich soil is caused by consolidation under self-weight and/or boundary loads. The rate of this process is controlled by the propagation rate of the thawing front, as well as the drainage of the melted water. The total amount of the thaw settlement depends primarily on the ice-lenses formed during the past freezing period, and this makes thaw consolidation process different from the conventional consolidation. A thermal-hydro-mechanical (THM) model for soil will be introduced. The model will capture the coupling effects among the three physical fields: temperature, seepage flow, and the stress field. The model will be based on partial differential equations (PDEs) representing conservation of energy, conservation of mass, and mechanical equilibrium, to describe the multi-physics features of the thaw consolidation process. The model will couple the Fourier's law for heat transfer and Darcy's law for fluid transfer in thawed soil in the presence of phase change. The settlement of soil is caused by thaw consolidation and drainage of water from melted ice-lenses. The three fields are fully coupled both through PDEs and inter-depency material properties, such as deformation moduli in mechanical field and the conductivities in the hydraulic and thermal fields as well. The model has been implemented in the finite element system to solve boundary value problems. A simulation of thaw settlement following a previous frost heave in frost-susceptible soil around a culvert passing below a road will be presented.

This work was funded, in part, by the Army Research Office, grant No. W911NF-08-1-0376.
Computer Science and Software Design

Session Chair: Mark Hsiao
A unified framework for multi-target tracking and collective activity recognition
Wongun Choi¹ and Silvio Savarese¹

¹Department of Electrical Engineering: Systems, University of Michigan, Ann Arbor, MI

We present a coherent, discriminative framework for simultaneously tracking multiple people and estimating their collective activities. Instead of treating the two problems separately, our model is grounded in the intuition that a strong correlation exists between a person's motion, their activity, and the motion and activities of other nearby people. Instead of directly linking the solutions to these two problems, we introduce a hierarchy of activity types that creates a natural progression that leads from a specific person's motion to the activity of the group as a whole. Our model is capable of jointly tracking multiple people, recognizing individual activities (atomic activities), the interactions between pairs of people (interaction activities), and finally the behavior of groups of people (collective activities). We also propose an algorithm for solving this otherwise intractable joint inference problem by combining belief propagation with a version of the branch and bound algorithm equipped with integer programming. Experimental results on challenging video datasets demonstrate our theoretical claims and indicate that our model achieves the best collective activity classification results to date.

This work was funded, in part, by ONR.
A scheduler for performance and energy optimization in data centers with heterogeneous tasks and machines
Xuejing He¹, Robert P. Dick¹, Xiaobo Fan²

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
²Google Inc.

This work describes a task scheduler that optimizes performance and energy consumption in data centers called Heterogeneous Adaptive Modeling Scheduler (HAMS). Typical data center workloads result in unbalanced loading of individual machines and particular resources within these machines. The resulting resource contention degrades performance. This is particularly severe in heterogeneous data centers where naive task assignment policies ignore machine and task heterogeneity, producing suboptimal loadings of machines. We describe a scheduler that can make task assignments that achieve 15% performance improvement over the most advanced existing task schedulers. Our scheduler captures the heterogeneity in data center machines using two models: a resource utilization model and a task performance model. We build these models by characterizing task resource utilization and performance under various loadings on different types of machines in the data center. We evaluate this task scheduler on 11 representative MapReduce workloads. We also use our task scheduler in conjunction with task concentration to minimize energy consumption, achieving on average 23% reduction in energy consumption while adhering to task latency requirements.
Lazy evaluation for topological mapping
Collin Johnson\textsuperscript{1}, Benjamin Kuipers\textsuperscript{1}

\textsuperscript{1}Computer Science and Engineering, University of Michigan, Ann Arbor, MI

We present an algorithm for probabilistic topological mapping that heuristically searches a tree of map hypotheses to provide a usable topological map hypothesis online, while still guaranteeing the correct map can always be found. Our algorithm annotates each leaf of the tree with a posterior probability. When a new place is encountered, we expand hypotheses based on their posterior probability, which means only the most probable hypotheses are expanded. By focusing on the most probable hypotheses, we dramatically reduce the number of hypotheses evaluated allowing real-time operation. Additionally, our approach never prunes consistent hypotheses from the tree, which means the correct hypothesis always exists within the tree.

This work was funded, in part, by grants from the National Science Foundation (CPS-0931474 and IIS-1111494), and from the TEMA-Toyota Technical Center.
A scalable parallel implementation of the plane wave time domain algorithm for solving time domain integral equations
Yang Liu¹, Eric Michielssen ¹.

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The computational complexity and memory requirements of direct schemes for evaluating transient electromagnetic fields produced by $N_s$ dipoles active for $N_t$ time steps scale as $O(N_t N_s^2)$. These costs can be reduced to $O(N_t N_s \log^2 N_s)$ by the multilevel plane wave time domain (PWTD) algorithm. Not surprisingly, the PWTD scheme has been used to accelerate marching on in time (MOT) -based integral equation solvers for analyzing transient scattering from complex structures. The majority of these implementations have been on serial computers though, limiting their applicability to real-life problems. To advance the capabilities of fast time domain integral equation solvers, parallel PWTD schemes and associated MOT solvers are called for. This poster first presents a parallel implementation of the multilevel PWTD scheme on a distributed-memory CPU cluster using MPI. The memory and computation loads are divided among compute-nodes by a hierarchical partitioning strategy, all PWTD calculation stages are parallelized using different partitioning techniques. The proposed parallelization strategy is provably scalable and exhibits favorable load balance and computation-to-communication ratios. The second part of the poster switch the gear to CPU-GPU clusters, which are clusters with one or more GPUs on each compute-node. In this work, most PWTD calculation stages, viz. spherical interpolation/filtering, field translations and near-field calculations are carried out on GPUs using CUDA-FORTRAN, while their CPU hosts control host-to-host and host-to-device communications. The proposed technique has been used to accelerate MOT solvers.

This work was funded, in part, by College of Engineering, University of Michigan.
Algorithm for scheduling power generators to meet N-k security requirements when transmission switching is employed
Kathryn Schumacher¹, Amy Cohn¹, Richard Li-Yang Chen²

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
²Quantitative Modeling and Analysis Department, Sandia National Laboratories, Livermore, CA

Most power grid systems are operated to be N-1 secure, meaning that the system can withstand the failure of any 1 component. More stringent security standards have been proposed where the power grid must be able to survive the simultaneous failure of multiple components (i.e. N-k). However, this improved reliability criterion significantly increases the number of contingency scenarios that must be considered. Additional complexity is introduced when taking into account transmission switching. This is a relatively inexpensive method of routing power flows in the grid that has been proposed as a way to reduce the cost of dispatching generators and improve robustness. In fact, under certain scenarios, survival is only possible by switching certain lines out of service. We present an algorithm for solving the unit commitment problem that addresses the challenges of the N-k security requirement and use of transmission switching during operation. We also analyze the algorithmic performance.

This work was funded, in part, by the National Science Foundation Graduate Research Fellowship Program.
An efficient branch-and-bound algorithm for optimal human pose estimation
Min Sun¹, Murali Telaprolu¹, Honglak Lee¹, Silvio Savarese¹.

¹Department of EECS, University of Michigan, Ann Arbor, MI

Human pose estimation in a static image is a challenging problem in computer vision in that body part configurations are often subject to severe deformations and occlusions. Moreover, efficient pose estimation is often a desirable requirement in many applications. The trade-off between accuracy and efficiency has been explored in a large number of approaches. On the one hand, models with simple representations (like tree or star models) can be efficiently applied in pose estimation problems. However, these models are often prone to body part misclassification errors. On the other hand, models with rich representations (i.e., loopy graphical models) are theoretically more robust, but their inference complexity may increase dramatically. In this work, we propose an efficient and exact inference algorithm based on branch-and-bound to solve the human pose estimation problem on loopy graphical models. We show that our method is empirically much faster (about 74 times) than the state-of-the-art exact inference algorithm (Sontag et al., 2008). By extending a state-of-the-art tree model (Sapp et al., 2010) to a loopy graphical model, we show that the estimation accuracy improves for most of the body parts (especially lower arms) on popular datasets such as Buffy (Ferrari et al., 2008) and Stickmen (Eichner et al., 2009) datasets. Finally, our method can be used to exactly solve most of the inference problems on Stretchable Models (Sapp et al., 2011) (which contains a few hundreds of variables) in just a few minutes.

This work was funded, in part, by the ONR grant N000141110389, ARO grant W911NF-09-1-0310, and the Google Faculty Research Award.
Genetic algorithm based electromagnetic optimization using efficient surrogate models
Abdulkadir C. Yucel¹ and Eric Michielssen¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

In recent years, optimization tools have become indispensable components of EM modeling and simulation frameworks. Specifically, the ones relying on genetic algorithms (GAs) have been successfully used to design a plethora of electromagnetic devices ranging from absorbers to microwave filters, waveguide devices, and antennas. The appeal of GAs stems from their capacity to straightforwardly treat mixed discrete-continuous design spaces and multiple objectives, as well as their ability to uncover strong local or even global objective function optima. Unfortunately, GAs often require the evaluation of objective functions for a large number (thousands or tens of thousands) of design candidates. This requirement for all practical purposes rules out the application of GAs in settings that require the execution of full-wave EM analysis tools as a precursor to the evaluation of the objective functions. The GA-based optimization of electromagnetic devices therefore often relies on (semi-) analytical, perturbation-based, or surrogate modeling methods for rapidly evaluating pertinent observables or objective functions. Unfortunately, semi-analytical and perturbation-based techniques are limited in scope. Surrogate models often lack accuracy, especially (i) when the dimensionality of the design space is high and/or (ii) when the pertinent observables or objective functions exhibit rapid variations or discontinuities. In this study, a new technique to construct accurate surrogate models for pertinent observables or objective functions is proposed. To permit the construction of surrogate models in high-dimensional design spaces, the proposed method leverages high dimensional model representations (HDMRs) to express pertinent observables or objective functions as finite sums of “component functions.” The lowest order component functions represent contributions of individual design variables to pertinent observables or objective functions, while high order ones reveal combined contributions of groups of design variables. The HDMR is constructed iteratively using a greedy search by starting from the lowest order component functions and including only higher order functions that contribute significantly to the pertinent observables or objective functions. The efficiency and accuracy of the proposed method will be demonstrated via its application to the selection of locations of stacked-patch microstrip antennas in a linear array and the placement of antennas on a ship.
Design and Manufacturing

Session Chair: Hai Nguyen
Design methodology for soft robotic actuators using fluid-filled fiber-reinforced elastomeric enclosures
Joshua Bishop-Moser

Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

Soft continuum robots allow for safe human interaction, impact resilience, complex controlled motions, and an array of other advantages. To realize robotic actuators with these properties, a set of fluid-filled fiber-reinforced elastomeric enclosures (FREEs) placed in a parallel configuration has been developed. These FREE structures can be found in nature from octopi to elephant trunks to tongues. The mobility of these FREEs has been determined from the equations describing the inextensibility of their fibers and the incompressibility of the fluid. The entire design space of cylindrical FREEs across all sets of fiber angles has been mapped, with their corresponding freedom and actuation directions determined. This mapping is then used to determine the mobility of FREEs when placed in parallel, using a constraint based method. The parallel configuration allows for multiple actuation directions, more stiffness when desired, and actuation directions not possible with a single FREE. A graphic user interface has been created which determines all viable FREE topologies from a set of desired motion patterns. To verify the accuracy of the fiber models, 5 case study parallel FREE structures were prototyped and tested in all actuation permutations. The motions were collected using 3-D motion capture and analyzed in Matlab. Most of the resulting motions matched closely with the predicted mobility directions.

This work was funded, in part, by the National Science Foundation
Integrating univariate control charts and Mahalanobis distance for process monitoring with near zero type II error

Weihong Guo¹, Chenhui Shao², Tae Hyung Kim², S.Jack Hu¹,², Jionghua (Judy) Jin¹, J.Patrick Spicer³, Mike Wincek³, and Hui Wang³

¹ Department of Industrial and Operations Engineering, The University of Michigan, Ann Arbor, MI, USA
² Department of Mechanical Engineering, The University of Michigan, Ann Arbor, MI, USA
³ Manufacturing Systems Research Laboratory, General Motors R&D Center, Warren, MI, USA

It is highly needed to ensure high product quality through online sensing monitoring for emerging manufacturing processes especially in producing mission-critical parts such as rechargeable batteries for electrical vehicles. The conventional control chart techniques widely used in many process monitoring systems were designed based on a pre-specified Type I error rate. However, to ensure the quality of mission-critical parts and reduce manual inspection at the same time, a near zero Type II error rate is desired for monitoring such processes. This research proposed an integrated monitoring scheme that targets at a near zero Type II error rate by integrating univariate control charts and Mahalanobis distance. This algorithm can be used to monitor multivariate processes in order to achieve near zero Type II errors. We illustrate how to set the control limits based on training data, validate the algorithm on test data, and study its performance with implementation on ultrasonic welding processes for battery manufacturing. After tuning the control limits, the SPC-M algorithm achieved an overall Type I error rate of 11.3% and Type II error rate of 0%. Applying these control limits on a production period of one month, the SPC-M algorithm achieved an overall Type I error rate of 21.6% and Type II error rate of 0%. With 0% Type II error rate, the SPC-M algorithm does not pass any suspected bad welds downstream.

Funding: The research is sponsored by the General Motors Collaborative Research Lab in Advanced Vehicle Manufacturing at the University of Michigan.
Harnessing light funneling for angle insensitive spectrum filters by nanoimprint
Andrew E. Hollowell\textsuperscript{1}, Yi-Kuei Ryan Wu\textsuperscript{2}, and L. Jay Guoe\textsuperscript{3}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109
\textsuperscript{2}Sandia National Laboratories, Albuquerque, NM 87123

Plasmonic resonant effects have the ability to manipulate and control optical waves independent of incidence angles. Recent advances in nanoscale fabrication have allowed the realization of novel structures designed to take advantage of the interaction between light and matter in the subwavelength regime. In this work, we propose a new scheme through resonant light funneling into nanoslits for angle robust reflective color filters and describe the fabrication through use of nanoimprint lithography (NIL). A variety of narrow bandwidth plasmonic based structures have been designed and applied as color filters; such as aperture perforated metal films, metal-insulator-metal (MIM) stacked arrays, and metallic resonant waveguide gratings. However, most plasmonic filtering effects have a large dependence on specific angles of incidence and have additionally been restricted to longer wavelengths leading to difficult implementation in the visible spectrum. Integrating the use of NIL, reactive ion etching, and precision metal deposition has allowed the fabrication of these reflective type angle independent color filters, with 40nm line width and 180nm pitch, based on resonant light funneling into nanoscale structures. Etch depths are modified to achieve specific wavelength resonances and grating periods are tailored for desired angle insensitivity. In addition to the reflective type CMY scheme, results are presented on precision nanoscale fabrication techniques used to confine the silver deposition to the top of the fused silica grating for fabrication of a transmissive type filter based on the red, green, blue, additive color scheme.
High-fidelity aerodynamic shape optimization of the blended-wing-body aircraft
Peter Zhoujie Lu\textsuperscript{1}, Joaquim R.R.A. Martins\textsuperscript{2}.

\textsuperscript{1}PhD Candidate, Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Associate Professor, Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

With the increasingly environmental concerns and the rise of the fuel prices, the aviation industry is facing a critical point where more fuel efficient aircraft options are needed in the near future. One of the unconventional aircraft configurations to target the environmental issues and fuel efficiency concerns is the blended-wing-body (BWB) configuration. The BWB is an alternative aircraft configuration characterized by an enlarged airfoil-shaped center body integrating payload, power plants and control surfaces. The BWB eliminates the tail present in conventional configuration and blends the fuselage with the wing. Its lift-generating center body section allows higher aerodynamic efficiency over conventional aircraft. The work presented applies high-fidelity aerodynamic shape optimization to an unconventional blended-wing-body configuration. The results of aerodynamic shape optimization are discussed. The geometry is parametrized through free-form-deformation with a B-spline volume. The mesh perturbation uses a parallel hybrid mesh warping scheme that applies linear elasticity-based warping scheme to perturb large-scale motions in the mesh and algebraic method to resolve local perturbations. A parallel structured multiblock flow solver is coupled to the ADjoint approach that applies automatic differentiation technique to the partial derivatives in the adjoint formulation. A gradient-based sequential-quadratic-programming optimization algorithm is used to solve the design problem. The drag-minimization shape optimization problem has 213 design variables and 121 constraints, and converges within 7 hours on a 16-processor cluster. The optimized blended-wing-body design achieves 31\% drag reduction compared to the baseline geometry.

\textit{This work was funded, in part, by Michigan/AFRL/Boeing Collaborative Center in Aeronautical Sciences (MAB-CCAS).}
Continuous, scalable micro/nano-patterning for optoelectronic and energy conversion applications

Jong G. Ok¹, Se Hyun Ahn¹,†, Moon Kyu Kwak²,‡, and L. Jay Guo¹,²

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
²Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
†Current address: Molecular Imprints, Inc., Austin, TX
‡Current address: School of Mechanical Engineering, Kyungpook National University, Daegu, Korea

Nanoimprint lithography (NIL) technology opens a way to high-throughput fabrication of nanostructures at great precision and low cost. NIL benefits from direct mechanical deformation of the resist material and therefore can realize resolutions beyond what conventional photo- or e-beam lithography can do that are limited by light diffraction or beam scattering. Since conventional NIL (i.e., thermal and UV) is basically a “stamping” process to transfer the micro/nano-scale patterns the master ‘mold’ contains to another substrate, the productivity is critically dependent on the mold preparation step and the area a mold can be fabricated up to. The typical mold fabrication methods that are based on e-beam lithography or interferometry, however, suffer from extremely low throughput and consequent high cost. To this end, developing continuous, high-speed, and scalable micro/nano-patterning processes is highly requested for practical uses. To address these issues, two main approaches are presented in this work: 1) NanoChannel-guided Lithography (NCL), and 2) Vibrational Indentation-driven Patterning (VIP). Specifically, NCL realizes the continuous patterning of high aspect-ratio nanogratings on UV-curable liquid resists based on the mechanical inscribing of a slice of mold and the selective wetting and self-stabilization of the accordingly delineated liquid lines. VIP utilizes a periodic indentation driven by the vertical vibration of the sharp tool onto any softer-than-tool materials, which enables the formation of real-time period-tunable gratings simply by controlling the vibration frequency and/or the substrate feeding speed. The application of these novel techniques to optoelectronic and energy conversion devices is demonstrated by optical waveguides and plasmonic filters.

This work was funded by the National Science Foundation.
Disassembly line balancing under high variety of end of life (EOL) states

Robert J. Riggs\textsuperscript{1}, Olga Battaïa\textsuperscript{2}, S. Jack Hu\textsuperscript{3}

\textsuperscript{1}Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, Mi
\textsuperscript{2}Laboratory of Informatics, Modeling and Optimization of Systems, École des Mines de Saint-Etienne, Saint-Etienne, France
\textsuperscript{3}Department of Mechanical Engineering, University of Michigan, Ann Arbor Mi

Previous approaches to the disassembly line balancing problem (DLBP) have ignored the variation in end of life (EOL) conditions a product can be in and its impact on determining the optimal line balance. The EOL state and the possibility of multiple recovery options of a product and its components (such as disposal, recycling, or reuse) can alter both the disassembly task times and what tasks need to be accomplished to disassemble the product in that particular EOL state. This EOL data is very difficult to insert into a line balancing model and have it solve in a timely manner. We show how generating a disassembly joint precedence graph from every EOL state the product can be in, including the possibility of different treatments for certain components or modules, is a tractable and effective way of giving proper weight and consideration to all EOL information. We use traditional line balancing methods from the literature to create a balanced serial transfer line using the example of the disassembly of a laptop computer. Simulation software is used to verify the results. We also develop a mixed integer program (MIP) to transform the serial transfer line into a parallel transfer line in order to increase the utilization and efficiency of the disassembly line. The parallel line balancing model uses the joint precedence graph as an input. To our knowledge, this is the first time a method is presented for applying a parallel line balancing model to disassembly line balancing.
Design and optimization of lithium-ion battery pack for PHEV applications
Nansi Xue¹, Wenbo Du¹, Thomas Greszler², Joaquim R.R.A. Martins¹

¹Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI
²Electrochemical Energy Research Laboratory, GM Research and Development, Honeoye Falls, NY

Plug-in hybrid vehicles (PHEV) have emerged as a viable alternative to conventional vehicles in an effort to improve fuel efficiency, lower operational cost as well as to reduce greenhouse emissions. The energy storage device of choice for PHEV applications are lithium-ion batteries due to their high energy density and long cycle life. Limited electric driving range as well as high battery cost, however, has hindered the market adoption of PHEV. This work highlights the effort done to improve the design of a lithium-ion battery pack by coupling a physics-based battery model with a numerical optimization framework. The objective is to identify cell designs and battery pack format that optimize battery pack properties while simultaneously satisfying all performance requirements. This is a nonlinear optimization problem with both continuous and integer design variables. A full lithium-ion sandwich cell based on porous electrode and concentrated solution theory is used to simulate the discharge of a lithium-ion cell. The nonlinearity of the governing equations and the transient nature of the cell variables make analysis of battery performance difficult and identification of optimal design non-trivial. We applied an augmented Lagrangian particle swarming optimization (ALPSO) algorithm that is able to overcome non-convexity and discontinuities in design spaces to converge towards the global optimum. Optimal cell design requires a balance between high energy capacity and efficient ion transportation within the cell.

This work was funded, in part, by GM/UM Advanced Battery Coalition for Drivetrains.
Earth Science and Remote Sensing

Session Chair: Catherine Walker
Detecting a persistent wind field in the boreal Canadian forest using polarimetric SAR and InSAR simulations

Michael L. Benson¹, Leland Pierce¹, Kamal Sarabandi¹

¹Department of Electrical Engineering & Computer Science, University of Michigan, Ann Arbor, MI

The 3D structure of Earth’s forested ecosystems is of great importance to their ecological functioning and societal uses. A combined SAR / InSAR approach is one methodology whereby a forest’s structure can be successfully estimated. Surface level wind fields in a forested region have been shown to produce a definable effect in SAR and InSAR images and thus may be detected remotely from an aircraft or satellite. Using the Michigan Fractal Tree Model as well as the Michigan Wind Model, we generated a database of numerous jack pine stands exposed to wind fields of varying force. We next used our SAR and InSAR simulators to determine the decorrelating effect of the wind fields on each stand, generating a database consisting of physical stand parameters including canopy height, dry biomass, and the number of included trees, as well as simulated remotely sensed parameters such as the fully polarimetric synthetic radar backscatter coefficients and the polarimetric scattering phase center for each stand. In addition we also included the remotely sensed data points for each stand without the presence of wind, for comparison. Using this database, we developed an estimate for a wind field’s speed using a stand’s physical parameters and its response to a SAR and InSAR instrument. We analyzed this estimate algorithm and found it to be highly accurate for our test stands of jack pine trees.

*This work was funded by the National Aeronautics and Space Administration.*
Spectral dependence of the response time of sea state to local wind forcing

David D. Chen¹, Scott Gleason², Christopher Ruf¹, Mounir Adjrad³

¹Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, Ann Arbor, MI, USA
²Department of Electrical and Computer Engineering, Concordia University, Montreal, Québec, Canada
³Department of Electronic and Electrical Engineering, University College London, London, UK

Measurements of wind near the surface of the ocean are essential to the determination of momentum and energy fluxes at the air/sea interface and to the forecasting of weather phenomena such as hurricanes. Bistatic remote sensing using L-band GPS signals has been proposed as an alternative to the conventional microwave radiometers and monostatic radar scatterometers for spaceborne ocean surface windspeed measurements. L-band waves can easily penetrate precipitation, and the cost and accommodation requirements of GPS receivers are significantly lower than their radiometer and scatterometer counterparts. However, L-band scattered signals are sensitive to waves with longer wavelengths than those sensed by conventional radiometers and scatterometers, which typically operate at higher frequencies. It is known that longer surface waves take more time to respond to surface winds, propagate further before decaying, and are generally less directly coupled to the local wind field. These factors could affect the ability of scattered GPS L-band signals to retrieve local wind fields. In this work, we attempt to quantify the relationship between the longwave spectrum and local winds by examining windspeed and surface slope measurements by buoys. Specifically, by applying a lag-correlator, it is observed that the average lag time decreases monotonically as the ocean surface wavelength decreases. It is found that 1 hour serves as a conservative upper bound on the average response time of L-band waves to local wind forcing.

This work was funded, in part, by the Natural Sciences and Engineering Research Council of Canada (NSERC) fellowship program.
Multi-model assessment of black carbon in Arctic snow and sea ice, an AeroCom analysis
Chaoyi Jiao¹, Mark Flanner¹, and AeroCom Contributors

¹Department of Atmospheric, Oceanic and Space Sciences, University of Michigan

Climate forcing from black carbon (BC) in Arctic snow has only been simulated with a few models, though many aerosol models exist. Here, we apply aerosol deposition fields from 25 models contributing to the two Phases of the Aerosol Comparisons between Observations and Models (AeroCom) project to simulate and evaluate within-snow BC concentrations and radiative forcing. We accomplish this by driving the offline land (CLM) and sea-ice (CICE) components of the NCAR Community Earth System Model (CESM) with different deposition fields and meteorological conditions from 2004-2009, during which an extensive Arctic field campaign of BC-in-snow measurements occurred. We find that models generally overestimate BC-in-snow concentrations in the Arctic compared with the observations, though there is substantial model diversity. The model bias of BC-in-snow concentration ranges from -9.7 ng/g to +24.8 ng/g for Phase I models, and from -9.3 ng/g to +42.6 ng/g for Phase II models. There is a high correlation between BC-in-snow concentrations averaged over grid cells spatially and temporally match with observations and averaged over all Arctic surface snow, revealing that the field campaign sampling sites provide a good representation of the Arctic as a whole. We apply the ratio between the simulated and observed BC concentrations to correct the BC-in-snow radiative forcing in the Arctic. The observationally corrected Arctic BC-in-snow forcing is 0.13 Wm⁻² for Phase I models and 0.11 Wm⁻² for Phase II models.
An investigation of Bjerknes compensation in the Southern Ocean in the CCSM4
Caroline Kinstle$^{1,2}$, Wilbert Weijer$^{2,3}$

$^1$Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI
$^2$Climate, Ocean and Sea Ice Modeling Group, CCS-2, Los Alamos National Laboratory, Los Alamos, NM
$^3$The New Mexico Consortium, Los Alamos, NM

Meridional heat transport in the climate system has contributions from both the ocean and the atmosphere; it is essentially symmetrical on a global scale with respect to the equator, although contributions from the ocean and the atmosphere differ in the separate hemispheres. It has been proposed that a variation in oceanic heat transport can be compensated by an opposing change in atmospheric heat transport so that the total heat flux in the system (which is balanced by top-of-the-atmosphere heat loss) remains nearly constant. This so-called Bjerknes compensation was shown to be true in the Northern Hemisphere, but it has not yet been tested in the Southern Hemisphere. This project aims to understand the relationship between poleward oceanic and atmospheric heat transport in the Southern Ocean by using the archive of the recently available Coupled Model Intercomparison Project Phase 5 (CMIP5). Specifically, this project uses output from the Community Climate System Model Version 4 (CCSM4), using time series of meridional heat transport in both the atmosphere and the ocean taken from the data and analyzed with statistical tools like coherence analysis. It is shown that the heat storage term in the Southern Ocean has a significant impact on the oceanic heat budget; as a result, no robust coherences between oceanic and atmospheric heat transports could be found at these southern latitudes.

*This work was funded, in part, by the Department of Energy.*
Inter-calibration of microwave radiometers using vicarious cold calibration
Rachael Kroodsma¹, Darren McKague¹, Christopher Ruf¹

¹Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI

The Global Precipitation Measurement (GPM) mission is an upcoming international multi-satellite mission that will measure precipitation from space. The GPM mission is unique in that it will utilize several different microwave radiometers on individual satellites to provide global coverage of precipitation measurements. Inter-calibration of the radiometers is a key aspect of the mission, intended to ensure that consistent measurements are made among the radiometers in the constellation. In order to inter-calibrate microwave radiometers, individual instrument characteristics have to be taken into account. These characteristics include center frequency, earth incidence angle (EIA), and orbital characteristics such as altitude and orbital inclination. One way to characterize and correct for these differences among the radiometers is by using a vicarious calibration technique which provides both cold and warm reference brightness temperatures (TBs) to calibrate the radiometers. Vicarious cold calibration uses the theory that the coldest TBs that a microwave radiometer observes are over the ocean with calm surface winds, no clouds, and minimal water vapor. This theory is used in the inter-calibration algorithm for GPM by use of the double difference. To calculate the double difference for two radiometers, the single differences for each radiometer are first computed. The single difference is found by taking the difference between the vicarious cold reference of the observed radiometer TBs and a vicarious cold reference from modeled TBs. The double difference is then the difference between the single differences of the two radiometers being inter-calibrated. The vicarious cold inter-calibration algorithm will be described and characterized here.

This work was funded, in part, by NASA Grant NNX10AM12H
Numerical modeling of the energy balance and the en-glacial temperature of Greenland ice sheet
Xiaojian Liu\textsuperscript{1}, Jeremy N. Bassis\textsuperscript{1}

\textsuperscript{1}Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI

The surface mass and energy balance of ice sheets links the response of ice sheets to atmospheric forcing. Historically, ice sheet model have relied on empirical parameterizations of these surface processes (e.g., positive degree days). More recently, global and regional climate models (e.g., RACKMO, MAR) have begun to incorporate sophisticated surface process models in an attempt to simulate ice sheet mass balance using a more physically based modeling approach. In this study we explore the limits of simple downscaling techniques to obtain the appropriate atmospheric forcing for surface energy balance models from global reanalysis products and evaluate the partition of uncertainties associated with downscaling and with various albedo, turbulent energy transfer and densification parameterizations. To accomplish this we have developed a simple physically based numerical model, the model is a one-dimensional multi-layer snow and ice model that accounts for both the surface energy balance and subsurface heating to evaluate the energy and mass balance in the upper part of Greenland Ice Sheet and calculates the surface energy balance, temperature and density evolution in the uppermost part of ice. It is run over the full annual cycle, simulating melting, temperature and density profiles throughout the seasons. We assess uncertainty in the forcing by driving the model using downscaled ECMWF ERA-Interim reanalysis data and comparing this with forcing derived from in situ AWS stations from Greenland Climate Network data and performs sensitivity studies using a suite of parameterizations for the albedo, turbulent fluxes and densification.
Diagnosing snow and sea ice radiative forcing in the Community Earth System Model

Justin Perket\textsuperscript{1,2}, Mark Flanner\textsuperscript{1}

\textsuperscript{1}Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Applied Physics, University of Michigan, Ann Arbor, MI

Earth’s albedo is evolving from changes in seasonal snow and sea-ice. Albedo feedback in climate models has been evaluated previously using the radiative kernel technique, where top-of-atmosphere (TOA) radiative fluxes associated with albedo change are calculated “offline” using pre-defined atmospheric states. This approach facilitates model intercomparisons, but can lead to inaccuracies associated with inconsistent surface and cloud states. We are incorporating a new diagnostic feature in the NCAR Community Earth System Model (CESM) that provides the instantaneous effect of land snow and sea ice on the TOA radiation budget at each time step. This diagnostic provides a precise measure of the radiative influence of model snow and sea ice, enables direct model comparison with observation-derived cryosphere radiative forcing (CrRF) estimates, and provides a means to evaluate the accuracy of the radiative kernel technique for diagnosing albedo feedback. Compared with observed northern hemisphere CrRF, we find that CESM produces a larger radiative effect for both land snow and sea-ice. Preliminary analysis shows the snow radiative effect in the Northern Hemisphere to be higher in coupled ocean-land-atmosphere simulations compared to standalone land simulations forced with atmospheric reanalysis data. The same is true for ice when comparing the coupled system to offline ice simulations in the Southern Hemisphere. Differences are less appreciable for sea-ice in the North or snow in the South. Studies are planned to assess the accuracy of different radiative kernels, evaluate reasons for model-observation discrepancies in cryosphere radiative forcing, and quantify model changes in CrRF under different forcing scenarios.

\textit{This work was funded, in part, by the National Science Foundation.}
Evaluating temporal evolution of surface albedo feedback using the CESM1
Adam Schneider¹, Mark Flanner¹

¹Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI

The surface albedo feedback (SAF) is one of the strongest positive feedback mechanisms operating in current climate. Previous studies quantify global mean SAF from equilibrium or century-scale climate simulations, but few studies examine decadal-scale variability in SAF. Here, we apply multiple ensemble members from CESM1 transient simulations of historical climate and future climate under different RCP scenarios, combined with two radiative kernels, to quantify temporal variability in SAF. Applying a sorting procedure, we show that variance in SAF decreases during periods of larger global mean temperature change. We examine this relationship for 30, 40, 50, and 60 year time periods to determine a minimum temperature change threshold for which the calculated feedback becomes representative of the model’s long time scale feedback. Interestingly, the standard deviation of SAF decreases to about 0.1 W/m²K with a global mean temperature change of about 0.5 K, irrespective of period length and climate state between 1850 and 2100, and continues decreasing rather monotonically with increasing temperature change. Consequently, we determine that periods with global mean temperature change of about 0.5 K or more are needed to eliminate noise in feedback. This also suggests that observations of SAF over such periods may be representative of the actual longer term SAF. Surprisingly, SAF remains relatively constant throughout the 21st century under the extreme RCP 8.5 scenario, even toward the end of runs when little seasonal snow and sea-ice remain.

This work was funded, in part, by the National Science Foundation.
The West Antarctic Ice Sheet is drained primarily by five major ice streams, which together control the volume of ice discharged into the ocean across the grounding line. The grounding line of Kamb Ice Stream (KIS) is unusual because the ice stream upstream of it is stagnant. Here, a set of surface features—shore-parallel, long wavelength, low amplitude undulations—found only at that grounding line are examined and found to be "pinch and swell" features formed by an instability in the viscous deformation of the ice. When a relatively competent layer is surrounded by lower strength materials, particular wavelength features within the layer may be amplified under certain layer thickness and strain rate conditions. The undulations at KIS grounding line are possible due to the relatively large strain rates and particular ice thickness at that location. Several data sets are used to characterize the surface features. High resolution surface profiles are created using kinematic GPS collected simultaneously with ice penetrating radar. The radar data are used to examine the relationship between surface shape and basal crevasses. Additional surface profiles are created using ICESat laser altimeter observations. Repeat GPS surveys of a strain grid across the grounding line yields strain rate information. Analysis of repeat observations over tidal cycles and multi-day intervals shows that the features are not standing or traveling waves. Together, these observations are then used to evaluate the contributions of elastic and viscous deformation of the ice in creating the grounding line undulations.

*This work was funded, in part, by the NSF.*
The Microwave Radiometer (MWR) flying on the Aquarius/SAC-D mission is a Dicke radiometer operating at 23.8 GHz (H-Pol) and 36.5 GHz (H- & V-Pol), developed by the Argentina Space Agency CONAE. This instrument was designed to complement Aquarius (NASA's L-band radiometer/scatterometer) by providing simultaneous spatially collocated environmental measurements such as oceanic wind speed and rain rate. MWR has 16 beams, 8 forward looking for 36.5 GHz (H- & V-Pol) and 8 aft-looking for 23.8 GHz (H-Pol) having Earth Incidence Angles (EIA's) 50.9°, 50.93°, 51.22°, 51.38°, 58.07°, 58.08°, 58.4° and 58.87°. The spatial resolution of MWR is 54 km. This mission was launched on June 10, 2011 and the satellite was placed at an altitude of 657 km in a sun-synchronous orbit with an inclination angle of 98°. Before retrieving any scientific information from the observed brightness temperature (TB) data, it is necessary to accurately calibrate the data to avoid any misinterpretations. The main objective of this work is to properly calibrate the TBs by making their absolute value and their relative variations in response to changes in incidence angle both are consistent with theoretical expectations. Firstly, a set of modeled/expected TBs were generated using vicarious cold technique for each incidence angle for both channels (23.8 GHz and 36.5 GHz). This technique also minimizes the effect of atmosphere. Secondly, the vicarious cold TBs were calculated for observed data for each day. Then the Root Mean Square (RMS) difference between observed cold TBs and model/expected cold TBs was minimized using linear regression.
Damage propagation: earthquakes, tidal waves, and breaking Antarctica's ice shelves
Catherine C. Walker¹, Jeremy N. Bassis¹, Helen A. Fricker², Robin J. Czerwinski¹

¹Atmospheric Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI
²Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA

The processes and mechanisms that drive the propagation of rifts in the ice shelves of Antarctica are not well understood, making it difficult to estimate the contribution by mass loss by iceberg calving to future predictions of sea level rise. In observing 72 rifts in 11 ice shelves over the past decade, we discovered a surprising and unintended result when we found that many rifts (fractures) propagated following the arrival of tsunamis at the Antarctic coast. In many cases, tsunami waves – which are only centimeters high in the open ocean, but have very long wavelengths – caused the calving (or production) of icebergs. In many cases, these sections of ice were large enough to be observed from spaceborne imagers. The December 2004 Sumatra earthquake and associated tsunami were observed to cause a 60x20 km iceberg to calve from the Larsen C Ice Shelf, and among others, cause large propagation in the 5 rifts in the Amery Ice Shelf, which is already close to disintegration. That southern hemisphere tsunamis affect the ice shelves was surprising (including the 2010 Chile earthquake), but even more so was the effects observed from the March 2011 tsunami emanating from Honshu, Japan in the northern hemisphere. We employ our observations and models of water-filled cracks in sea walls to exhibit the effects of tsunamis on the ice fronts of Antarctica. These observations fortify previously-hypothesized links between natural events like earthquakes and their associated tsunamis to ice shelf rifting or mass loss (iceberg calving) in the polar regions, which contribute to estimates of sea level rise.

This work was funded, in part, by the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF).
Exploiting passive microwave radiometer data in coastal regions: demonstration of wind retrieval in the Great Lakes using SSM/I

John Xun Yang¹, Darren Mckague¹

¹Department of Atmospheric, Oceanic and Space Science, University of Michigan, Ann Arbor, MI

We present a method for using Special Sensor Microwave/Imager (SSM/I) data in coastal regions and demonstrate the application of wind retrievals in the Great Lakes. Passive microwave radiometers have been widely used over open ocean, but the data in near land regions are often not used because of the mixed signal from both land and water. For example, wind retrievals using SSM/I data are typically unavailable within around 100 km of any coastline, ruling out wind retrievals over smaller bodies of water such as inland lakes. We show that a procedure considering data geolocation, antenna pattern correction and land-water masks can produce data from which geophysical parameters may be retrieved. Specifically, wind retrievals over the Great Lakes are demonstrated and validated with buoy data. Firstly, we show that geolocation can affect significantly on coastal retrieval and needs to be well aligned. Secondly, the land contamination on measured brightness temperature (TB) is reduced by subtracting the land area portion within the antenna field of view, where antenna side lobe effect is accounted rather than merely considering the main beam. Lastly the wind retrieval algorithm is applied to the corrected TB to obtain wind speed. The TB data from spacecraft platform F-13 has been used, which shows robust improved correlation with buoy measured wind speed. This method is not restricted to SSM/I and wind retrievals but rather can be applied to other relevant data for general retrieval purposes.
Improving weather prediction and regional climate modeling through the use of variable-resolution global atmospheric models

Colin M. Zarzycki\textsuperscript{1}, Christiane Jablonowski\textsuperscript{1}

\textsuperscript{1}Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, Ann Arbor, MI

The use of variable-resolution general circulation models (GCMs) harbors the potential for vast improvement in the community’s ability to simulate the atmosphere. Such setups allow for non-uniform grid spacing, permitting resolutions as fine as 10 kilometers over regions of interest such as low-latitude ocean basins where cyclogenesis of traditionally underresolved tropical cyclones occurs. These scales have historically been restricted to limited area (or regional climate) models (LAMs) due to the burdensome computational demand of running global models at increased resolutions. Variable-resolution global models bridge this gap and serve to provide affordable high resolution within a global framework while eliminating the need for externally-forced and possibly numerically and physically inconsistent boundary conditions required by LAMs. A statically-nested, variable-mesh option has recently been introduced into the National Center for Atmospheric Research (NCAR) Community Atmosphere Model’s (CAM) Spectral Element (SE) dynamical core. We present short-term CAM-SE model simulations of historical tropical cyclones and compare the model’s prediction of storm track and intensity to other global and regional models used operationally by hurricane forecast centers. Additionally, we explore the model’s ability to simulate other weather phenomena traditionally unavailable to global modelers such as mesoscale convective systems and precipitation lines associated with frontal passages. We also present hurricane statistics from long-term simplified aquaplanet climate experiments to showcase the model’s ability to resolve storms on a selective regional basis as well as consider the potential computational benefits in using a highly scalable, variable-resolution setup as an operational tool for both weather and climate prediction.

\textit{Part of this work was completed while the author visited the Issac Newton Institute for Mathematical Sciences at the University of Cambridge. The support of the institute is greatly acknowledged.}
Energy

Session Chair: I-Ning Hu
Model-predictive cascade mitigation in electric transmission networks with energy storage
Mads Almassalkhi$^1$ and Ian Hiskens$^1$

$^1$Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

In electric power networks, the economic dispatch problem allows computation of an economically optimal hour-by-hour trajectory, which the system operator tracks via available generators and forecasted load. However, if a disturbance occurs, the operator will need to modify his economical trajectory to prevent cascading failures. This requires the formulation of an emergency (safety) controller, which responds quickly to a disturbance and drives the system to a secure state, from which economic dispatch can be re-initiated and normal (economic) operation can resume. In this work, we propose to employ a minute-by-minute receding-horizon model-predictive control (MPC) scheme to provide feedback against large disturbances (e.g. line outages). Power flows across transmission lines incur $I^2R$ losses, which contribute to line heating and, in some cases, can cause a line to be taken out of service (i.e. tripped) to prevent dangerous sagging/overheating. To mitigate line tripping, we consider a linearized thermodynamic transmission line model within our MPC scheme. In addition, our MPC scheme utilizes a lossy DC optimal power flow framework and takes generator ramp-rate limits, selective load shedding, energy storage dynamics, and available renewable energy into account to describe the optimal cascade mitigation scheme. Simulations are conducted on the standard IEEE reliability test-system “RTS-96” to illustrate the MPC feedback mechanism, which optimally utilizes energy storage devices in emergency control to relieve congestion and thermal overloads and overcome generation ramp-rate limiting constraints.

This work was funded, in part, by Department of Energy
Lithium transition metal dichalcogenides (TMDCs) intercalation compounds for batteries: synthesis and study of physical and electrochemical properties

Erica Chen¹ and Pierre Ferdinand P. Poudeu¹

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, 48109, USA

Layered transition metal dichalcogenides (TMDCs) with general formula TQ₂, have emerged as suitable positive electrode materials¹. Structurally, a layer of the transition metal atom (T) is sandwiched by two layers of chalcogenide atoms (Q). The resulting \{TQ₂\} slabs are stacked together with weak van der Waals interaction between them. This interlayer spacing in TMDCs can be filled by ions such as Li⁺, Na⁺, Cu⁺ Ag⁺ etc. to form intercalated compounds suitable for use as positive electrodes in rechargeable batteries (Li/MoS₂, Li/TiS₂)². The intercalation reaction generally results in some increases in the interlayer separation and may also induce interesting subtle changes on the structure and physical properties of the host material. Among known Li containing TMDCs, LiₓTiS₂ had emerged as a cathode material for high energy density batteries. The advantages of LiₓTiS₂ as cathode material originate from structural stability upon Li intercalation up to x ~1, and the reversibility of the insertion reaction³. Recently, it was demonstrated that Ni substitution at Ti sites in LiₓTi₁₋ₓNiₓS₂ compounds changes the sulfur stacking sequence in the structure from hexagonal to cubic⁴. This change in the S packing structure raises the Fermi energy, E_g of the TiS₂ layers in the LiₓTiS₂ structure by ~0.3 eV upon going from cubic to hexagonal stacking⁴. In addition, it was also shown that Li diffusion in the hexagonal layered LiₓTiS₂₋ₓSeₓ is strongly altered by the degree of Se substitutions at S sites⁵. An investigation on the effect of atomic substitutions at both Ti and S sites in LiₓTi₁₋₂MₓS₂₋₂ySeᵧ (M = V, Cr and Mn) on the structure of the Ti₁₋₂MₓS₂₋₂ySeᵧ layers, the Li uptake (x values) and the electrochemical performance of LiₓTi₁₋₂MₓS₂₋₂ySeᵧ as cathodes in Li-ion half-cells is presented here.
Transition metal nitrides and carbides based supercapacitors for future energy-storage systems
Abdoulaye Djire⁠¹, Priyanka Pande⁠¹, Alice Sleightholme⁠¹, Paul Rasmussen⁠¹, and Levi T. Thompson⁠¹

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI 48109-2136 USA

The transition to a more sustainable energy economy will require new, better performing materials for the conversion of renewable energy sources into fuels and the storage of these fuels. Our research focuses on controlling the structure and composition at the nanometer scale as a strategy to produce materials with extraordinary properties. We discovered that nanostructured nitrides and carbides possess high capacitances in aqueous electrolytes. The basis for these high capacitances appears to be a pseudocapacitive charge storage mechanism. Using electrochemical characterization techniques such as cyclic voltammetry, chronopotentiometry and electrochemical impedance spectroscopic methods we were able to define key aspects of the charge storage mechanism for early transition metal nitrides and carbides.
Direct conversion of oxygenated fuels to power using solid oxide fuel cells
Brittany Lancaster\textsuperscript{1} and Suljo Linic\textsuperscript{1}

\textsuperscript{1}Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

Technology advances and world population growth will demand increasing amounts of electricity generation. Over the last several decades, intermediate temperature (600-800°C) solid oxide fuel cells (SOFCs) have been developed that can generate electricity with very high efficiencies from carbonaceous fuels. Concurrently, biofuels including ethanol and butanol have been developed from renewable plants and other biological sources. These fuels have a lower carbon footprint than conventional fossil fuels. SOFCs run on these renewable fuels would create a highly efficient process to generate electricity for tomorrow's technologies with a small carbon footprint. Current commercial nickel SOFCs cannot be run directly on oxygenated fuels such as ethanol or butanol because the carbon from the fuel quickly degrades the catalyst on the anode, or fuel side of the cell. In this work, fuel cells with tin/nickel surface alloy anodes are made and tested with oxygenated fuels such as ethanol and butanol. The performance and resistances across the fuel cells are monitored over time using chronoamperometry, linear sweep voltammetry, and electrochemical impedance spectroscopy. When run on ethanol, the nickel catalysts show changes in performance over time whereas the tin/nickel surface alloy catalysts have very stable performance. The nickel catalysts also show more degradation over time than the alloy catalysts under the same conditions.

\textit{This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE 1256260.}
We have successfully utilized all-conjugated copolymers in ternary blend systems for organic solar cell applications. These novel copolymers were synthesized by the newly discovered Ni-catalyzed chain growth polymerization, which enabled highly controlled assembly of diblock and gradient copolymers. Their chemical composition consisted of units of 3-hexylthiophene (the monomer of the widely-studied P3HT) along with either 3-((hexyloxy)methyl)thiophene (3HOMT) or 3-hexylselenophene (3HS). The copolymers were incorporated in solution-processed polymer-fullerene solar cells, and the device performance and nano-scale morphology of the active layer were investigated. Bulk measurements of the solar cell performance showed that while the P3HT-P3HOMT diblock is inferior to P3HT homopolymer as the primary donor species, incorporating small weight fractions of the copolymer into P3HT:ICBA blends could enhance device efficiencies for both as-cast and annealed films. Energy-filtered TEM was employed to characterize the bulk heterojunction morphology of the active layer, providing strong evidence that the copolymer additive had the effect of restricting the sizes of the polymer and fullerene phases, facilitating exciton dissociation at the donor-acceptor interface. Based on the open-circuit voltage of the devices and the UV/Vis absorption spectra, it is believed that the copolymer also modified the electronic band structure and optical properties of the thin film. Preliminary investigations of the P3HT-P3HS copolymers also show promise in opening new avenues for morphological control of the bulk heterojunction. Further studies are underway to clarify the role of these conjugated copolymers in modifying the bulk heterojunction morphology and the active layer optoelectronic properties.

*This work was supported as part of the Center for Solar and Thermal Energy Conversion, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science.*
‘Excluded-volume effect’, ‘Faradaic convection’, and their impacts on galvanostatic transport in battery separators

Jing Liu¹ and Charles W. Monroe¹

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

A mathematical model is implemented to simulate galvanostatic transport in battery separators. The model is constructed on the basis of the concentrated solution model developed by Newman, and takes further steps to account for the ‘excluded-volume’ and ‘Faradaic-convection’ effects. The excluded-volume effect is considered by adding an equation of state to the theory, stating the relation between the partial molar volumes of all the species in the electrolytic solution and their contents. Incorporation of the state equation enables the model to account for how local solution density varies with local ion concentration. Analysis is provided to show that during transport in relatively concentrated solutions, the excluded-volume effect is of great importance. Faradaic convection of the electrolyte is induced by heterogeneous reactions at electrode surfaces. Material exchanges between the solid and liquid phases in these reactions lead to the movement of the battery separator as a whole. We show that this convection significantly affects transport when the cell dimension is small and the applied current is high. In the model, Faradaic convection is handled by introducing a moving boundary to the governing system of equations, whose velocity is determined by the electrode reactions. The model is solved both analytically and numerically for a one-dimensional cell containing three species (solvent, cation and anion). Analytical results show that excluded volume and Faradaic convection impact both limiting currents and concentration profiles significantly. A numerical simulation of galvanostatic polarization measurements rationalizes previously unexplained experimental results.

This work is funded by Bosch Energy Research Network.
Engineering in Biological Systems

Session Chair: Asish Misra
Chemotactic symphony on a chip: CXCR7 conducts CXCL12-isoform-specific chemotaxis and sensitization of CXCR4 expressing breast cancer cells in a microfluidic source-sink-migration model

Stephen P. Cavnar\textsuperscript{1}, Paramita Ray\textsuperscript{2}, Pranav Moudgil\textsuperscript{1}, S. Laura Chang\textsuperscript{3}, Kathryn E. Luker\textsuperscript{2}, Jennifer J. Linderman\textsuperscript{3}, Shuichi Takayama\textsuperscript{1,4}, and Gary D. Luker\textsuperscript{1,2,5}

\textsuperscript{1}Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Center for Molecular Imaging, Dept. of Radiology, University of Michigan Medical School, Ann Arbor, MI
\textsuperscript{3}Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{4}Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor
\textsuperscript{5}Department of Microbiology and Immunology, University of Michigan Medical School, Ann Arbor, MI

The chemokine CXCL12 is involved in the progression and metastasis in 20+ cancer types. Most studies of CXCL12 focus on the $\alpha$-isoform of the ligand. However, 6 human isoforms are expressed in time- and organ-specific manners throughout development and disease. We used a novel microfluidic source-sink-migration model of CXCL12-isoform secretion (source cells), scavenging via CXCR7 (sink cells), and signaling via CXCR4 (migrating cells) to identify isoform-specific roles in metastasis. We used time point and kinetic tracking of CXCR4+ cells to reveal that, opposite to standard transwells, CXCL12-$\gamma$ induced more chemotaxis than $\alpha$- and $\beta$-isoforms. CXCL12-$\gamma$ drove higher recruitment of $\beta$-arrestin-2 via CXCR4, lower recruitment of $\beta$-arrestin-2 via CXCR7, and lower CXCR7-dependent scavenging relative to other isoforms. By using scavenging-incompetent CXCR7 and by diluting the fraction of CXCL12-secreting cells we found two regimes of CXCR7 relevance in chemotaxis: 1) high CXCL12 requires CXCR7-scavenging, and 2) low CXCL12 bypasses the need for CXCR7-dependent scavenging. Treatment with clinical antagonist AMD3100 was unable to fully inhibit chemotaxis towards high levels of CXCL12-$\alpha$ and was surprisingly ineffective at inhibiting even low levels of $\beta$- and $\gamma$-isoforms. We found transcript expression of all three isoforms in tumors and bone marrow of relevant mouse models. In human tissues, CXCL12-$\alpha$ and -$\beta$ were expressed in all stages of breast cancer, whereas the $\gamma$-isoform was only expressed in advanced stage III and IV. We found that despite lower reported affinity for its receptor CXCR4, CXCL12-$\gamma$ acted as a high-affinity ligand and may have a distinct role in cancer metastasis.

This work was supported by United States National Institutes of Health grants R01CA136553, R01CA136829, R01CA142750, and P50CA093990. S.P.C. was supported on Advanced Proteome Informatics of Cancer Training Grant. Grant #T32 CA140044.
Multi-scale agent-based modeling of cancer cell chemotaxis within a microfluidic assay

S. Laura Chang¹, Stephen P. Cavnar², Shuichi Takayama², Gary Luker²,³,⁴, Jennifer Linderman¹

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
²Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
³Department of Radiology, University of Michigan, Ann Arbor, MI
⁴Department of Microbiology and Immunology, University of Michigan, Ann Arbor, MI

The chemokine CXCL12 is a major chemotactic proponent in breast cancer. CXCL12 gradients within the tumor environment are thought to drive CXCR4+ cancer cells to invade and extravasate. A second receptor to CXCL12, CXCR7, is also present in the tumor environment. Understanding how CXCR7 can shape ligand gradients on a molecular level, and influence cancer cell chemotaxis within the tissue scale, is unclear. In addition, CXCL12 exists as multiple isoforms, yet studies examining its role in cancer have only focused on one isoform. These isoforms have varying affinities for cell surface receptors and glycosaminoglycans, as well as experimental device surfaces, ultimately changing the presentation of the ligand to the receptor. These complex interactions complicate our understanding of chemotactic gradient formation, sensing, and its role in cancer. In order to investigate the molecular mechanisms that regulate gradient formation and cancer cell responses to these gradients, we built a data-driven multi-scale agent-based model that simulates chemotaxis within a microfluidic assay. CXCR4+, CXCR7+, and CXCL12-secreting cells are agents that move and interact on a lattice. Each agent contains a set of ordinary differential equations that describe the internalization, recycling, and degradation of CXCL12 and its receptors. Therefore, the cells update and respond to their environment. We constructed and validated the model based on experimental data. We find that the presence of CXCR7+ cells significantly alters CXCL12 gradients, thus controlling CXCR4+ cell migration. Using sensitivity analysis, we identify key events in the CXCL12/CXCR7 pathway that can be targeted to inhibit CXCR4+ cell migration.

This work was funded, in part, by the National Science Foundation.
In vitro investigation of white-tailed deer antlerogenic progenitor cells
Daley ELH¹, Alford Al¹, Goldstein SA¹

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

As the only adult mammalian organ capable of complete regeneration, cervid antler has unique potential as a model for improving regenerative medicine. However, we lack a basic understanding of the antlerogenic progenitor cells (APC) central to antler regeneration or how they compare to other cervid mesenchymal stromal cells (MSC). Using cells harvested from wild white-tailed bucks (*Odocoileus virginianus*) we performed a novel in vitro comparison of APC and MSC proliferation, self-renewal capacity and mesenchymal lineage differentiation. Our data suggest that both APC and marrow-derived MSC form similar colony numbers, an indicator of self-renewal. While MSC exhibit adipogenic, osteogenic and chondrogenic differentiation capacity, APC may be more committed chondrocyte/osteoblast progenitors. Qualitative differences in chondrogenic micromass staining suggest that APC-derived chondrogenic cells in vitro generate a collagenous matrix of reduced proteoglycan content compared to MSC. We detected osteocalcin in APC and MSC, indicating osteoblastic differentiation capacity. Initially greater alkaline phosphatase activity suggests earlier APC osteoblastic commitment, but this did not lead to greater per-cell mineralization. In addition, rapid APC proliferation is thought to foster fast antler growth; we found that APC in vitro expand less rapidly than MSC. This suggests proliferation is highly variable or abetted by other processes in vivo. In micromass cultures, however, APC had similar cell number per area compared to MSC, yet also greater apoptosis. This behavior outwardly resembles an unusual feature of the antler tip. There, robust and widespread apoptosis colocalizes with, and may regulate, proliferation.

*This work was funded by NIH ROI-AR051504.*
Silicon and parylene intracortical neural probes for chronically-stable recording
Daniel Egert¹, Rebecca L. Peterson¹, and Khalil Najafi¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Next-generation neuroprostheses, which aiding the paralyzed to regain independence by controlling artificial limbs, are being presently employed in clinical pilot studies. A key requirement for control of motor neuroprosthetics is the ability to record brain activity of awake, freely behaving hosts accurately enough to distinguish action potentials from single neurons. To date only intracortical neural probes can provide the required specificity. However, the high spatial resolution of intracortical neural probes comes at the cost of a high degree of invasiveness; the host immune response often inhibits chronic recording. This project pursues two approaches to mitigate the immune response to implanted neural probes and its impact on their performance. The developed neural probes consist of silicon or Parylene formed into millimeter-long, needle-like shanks hosting multiple microelectrodes. One technology supports individual electrodes that are placed at the end of very fine and flexible needle extensions to the shank. Before implantation, the needles are locked into a protected position using a biodissolvable glue. After implantation they deploy away from the shank into healthy tissue, where they act like satellites, floating almost freely inside the brain tissue. This is expected to greatly increase biocompatibility. A second technology, based on the flexible polymer Parylene, addresses a tradeoff between designing a shank large enough to be reliably implanted and the increase in tissue damage with size of the shank. The developed process allows formation of sharp tips, and the strategic design of the shank increases its mechanical robustness without significantly increasing its size.

This work was funded, in part, by the DARPA Hybrid Insect MEMS program under grant # N66001-07-1-2006.
Pore size effect on chondrogenic differentiation of human mesenchymal stem cells in vitro and cartilage formation in vivo on nano-fibrous PLLA scaffolds

Jiang Hu¹, Melanie J. Gupte²#, Haiyun Ma¹, Kai Feng³, Ganjun Feng¹,⁴, Guiyong Xiao¹,⁵, and Peter X. Ma¹,²,³

¹Department of Biologic and Material Sciences, University of Michigan, Ann Arbor, MI
²Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
³Macromolecular Science and Engineering Center, University of Michigan, Ann Arbor,
⁴Department of Orthopedic Surgery, West China Hospital, Sichuan University, Chengdu, China
⁵School of Materials Sciences and Engineering, Shandong University, Jinan, P. R. China

The pore size of scaffolds plays an important role in cell attachment, migration, and differentiation. It has been reported that pore size affects the differentiation of chondrocytes, but optimal pore size is inconclusive among different scaffolds. Furthermore, the effect of pore size on chondrogenic differentiation of stem cells remains unclear. Previously, we have demonstrated that poly-L-lactide (PLLA) two-dimensional nano-fibrous (NF) matrix promoted human bone marrow-derived mesenchymal stem cell (hMSC) commitment along the chondrogenic route. Chondrogenic differentiation of hMSCs was also supported by our three-dimensional (3D) porous NF scaffolds in vitro. In this study, we compare the chondrogenic differentiation of hMSCs on NF scaffolds with small pore (125-250 μm) or large pore (425-600 μm) size. It was found that small-pore scaffolds were better in supporting chondrogenic differentiation in vitro with TGF-β1 stimulation. This was shown by higher marker gene expression level at 2 weeks and cartilage-specific extra-cellular matrix deposition at 2 and 4 weeks. Following 4w chondrogenic culture and 8w mouse subcutaneous implantation, small-pore scaffolds supported avascular cartilage formation, but large-pore scaffolds contained only fibrous tissue. Therefore, small-pore scaffolds enhanced chondrogenic differentiation in vitro and cartilage formation in vivo compared to large-pore scaffolds. This study provides a useful method to control the cartilage regeneration process with highly designed pore architecture of porous NF scaffolds.

This work was funded, in part, by the National Institutes of Health and China Scholarship Council.
Finite element model predicting the initial superior labrum anterior posterior lesion with a rotator cuff tear

Eunjoo Hwang $^{1,2}$, Richard Hughes $^{1,3,4}$, James Carpenter $^4$, Mark Palmer $^{1,2}$

$^1$Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
$^2$Department of Kinesiology, University of Michigan, Ann Arbor, MI
$^3$Department of Industry and Operations Engineering, University of Michigan, Ann Arbor, MI
$^4$Department of Orthopaedic Surgery, Medical School, University of Michigan, Ann Arbor, MI

The labral pathology, Superior Labrum Anterior-Posterior (SLAP) lesion, is commonly accompanied by rotator cuff tears (RCTs). Despite of active studies on each tear, the relationship between two tears is still unclear due to the methodological difficulties. For multiple quantitative tests and observation of kinematics inside tissues, we generated a computational finite element (FE) model. However, the number of FE modeling is limited due to the complex anatomy and composition of the labrum. Thus, the purpose of study was to develop an anatomically accurate FE model including the glenoid labrum to examine the relation between SLAP lesions and RCTs. We acquired the geometries of the glenoid bone, glenoid cartilage, labrum, humerus, and humeral cartilage from CT datasets. Especially labrum was obtained by Boolean operation. The path of biceps was determined by the other relevant structures. The geometry of each structure was captured by surface meshes by Amira and changed to the hexahedral meshes using HyperMesh. The material properties of each tissue were from other studies. The loading and boundary conditions were matched with controlled experimental setting. The analysis program was LS-DYNA. We compared between predicted and measured displacements for validation. We translate the humerus in validated FE model by 5mm to represent RCTs. A FE model showed the location of the highest stress, which is typical initial area of SLAP lesions. The correspondence between the FE model and clinical observation supports the use of this model to study the pathology of the SLAP lesion accompanying with RCTs.
Development of targeted “smart” particles for silencing breast cancer metastases
Neha Kaushal\(^1\), Yasemin Yuksel Durmaz\(^1\), Yen-Ling Lin\(^1\), and Mohamed E. H. El-Sayed\(^1,2\)

\(^1\)Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\(^2\)Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI

Our goal is to utilize β-cyclodextrin (β-CD) to develop asymmetric “smart” nanoparticles for enhanced cytoplasmic delivery of silencing RNA (siRNA) molecules into breast cancer cells as a novel strategy to suppress metastatic spread of breast cancer. Specifically, we grafted hydrophobic hexyl methacrylate (HMA) and pH-sensitive dimethyl aminoethyl methacrylate (DMAEMA) monomers from the secondary face of β-CD via acid-labile hydrazone linkages forming amphiphilic P(HMA-co-DMAEMA) grafts. We converted 50% of the DMAEMA units to cationic trimethyl aminoethyl methacrylate (TMAEMA) to condense the siRNA molecules via electrostatic interaction. We conjugated polyethylene glycol (PEG) chains to the primary face of β-CD cone, which can be further functionalized to display a specific targeting ligand. These “smart” particles are engineered to “sense” the drop in endosomal pH, which triggers hydrazine linkage hydrolysis and release of membrane-active P(HMA-co-DMAEMA-co-TMAEMA) grafts that rupture the endosomal membrane and release their siRNA cargo into the cytoplasm. The objective of this research is to silence RhoC protein expression, which is overexpressed in metastatic breast cancer cells. Earlier research showed selective RhoC knockdown at the mRNA and protein levels using siRNA inhibited breast cancer cell proliferation, migration, and invasion \textit{in vitro} and tumor growth and angiogenesis \textit{in vivo}.

\textit{This work was funded, in part, by Susan G. Komen Foundation.}
Engineering microbial systems for cellulosic isobutanol production using ecology and evolutionary theory

Jeremy Minty$^1$, Alissa Kerner$^2$, Marc Singer$^1$, Lawrence Lai$^1$, Ann Lesnefsky$^1$, Fengming Lin$^1$, Yu Chen$^1$, Ted Zaroff$^1$, Ian Faulkner$^2$, Chang-Hoon Bae$^1$, Jungho Ahn$^1$, Artur Veloso$^3$, and Xiaoxia Nina Lin$^{1,2}$

$^1$Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
$^2$Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
$^3$Bioinformatics Graduate Program, University of Michigan, Ann Arbor, MI

Microbial biofuels produced from lignocellulosic biomass are a promising renewable energy source, but tremendous research efforts are needed in engineering microorganisms with desired properties. By integrating ecology and evolutionary theory with synthetic biology, we are developing innovative strategies for engineering microbes for cellulosic biofuel production. We focus on two key areas: improving stress tolerance phenotypes to generate more robust biofuel production hosts, and improving microbial conversion of lignocellulose to biofuel products. For proof-of-concept, we focus on tolerance and production of isobutanol, a promising next-generation biofuel. Stress tolerance is a complex phenotype with a poorly understood genetic basis. We are developing a comprehensive approach to elucidate and improve the genetic basis of isobutanol tolerance. Our approach entails experimentally evolving isobutanol tolerant microbes and then using whole genome resequencing to reverse engineer mechanisms and genetic bases of tolerance. We then use these results to predict candidate genetic loci for targeted mutagenesis using Multiplex Automated Genome Engineering (MAGE). In the second portion of this project, we explore a novel microbial engineering strategy: the design, theoretical analysis, and construction of a microbial consortium consisting of multiple species which cooperate to directly convert cellulose to isobutanol. Three microbial specialists are utilized: a cellulytic specialist, which secretes enzymes to hydrolyze lignocellulose into hexose and pentose saccharides, and hexose and pentose specialists which ferment these respective saccharides to isobutanol. We have experimentally demonstrated conversion of microcrystalline cellulose and lignocellulosic biomass to isobutanol with the consortium, achieving titers up to 1.8 g/L and yields 60% of theoretical.

This work was supported by NSF (EEC 0926926, CBET 1055227) and the University of Michigan Office of the Vice President for Research.
Effect of poly(ethylene glycol) spacers on the vascular targeting of particles to endothelium in blood

Peter Onyskiw¹ and Omolola Eniola-Adefeso¹

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

Vascular targeting is an intriguing means for therapeutic treatment and diagnosis of cardiovascular diseases such as atherosclerosis. To target diseased tissue particulate carriers are modified to contain antibodies or epitopes, such as anti-intercellular adhesion molecule-1 (anti-ICAM-1) and Sialyl Lewisα. Along with targeting moieties, poly(ethylene glycol) spacers are used to improve circulation time by reducing protein adsorption on the surface of particles. Though the use of poly(ethylene glycol) to reduce protein adsorption is well studied, little work has been done on examining the effect of poly(ethylene glycol) on adhesion dynamics; specifically in human blood flow. Here we exam the influence of different molecular weight poly(ethylene glycol) spacers on particle adhesion dynamics to inflamed human endothelial cells in blood. Polystyrene nano/microspheres were grafted with poly(ethylene glycol) spacers of different lengths and densities to serve as a linker between particle surface and targeting ligand – anti-ICAM-1 or Sialyl Lewisα. Targeted particles in human blood were then perfused over a monolayer of IL-1β stimulated human umbilical cord endothelial cells using a parallel plate flow chamber at shear rates of 200 s⁻¹, 500 s⁻¹, and 1000 s⁻¹. Poly(ethylene glycol) spacers were shown to improve binding flux of antibody-coated microspheres to activated cells but had no effect on the binding flux of Sialyl Lewisα –coated microspheres and the dynamics appear to be a function of PEG surface conformation and blood shear rate.

This work was funded, in part, by the American Heart Association.
Bioeffects of acoustic droplet vaporization (ADV) on endothelial cells
Robinson Seda\textsuperscript{1}, David Li\textsuperscript{1}, J. Brian Fowlkes\textsuperscript{2}, Joseph L. Bull\textsuperscript{1}

\textsuperscript{1}Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Radiology, University of Michigan, Ann Arbor, MI

Gas embolotherapy adds selectivity to conventional embolotherapy through vaporization of liquid microdroplets droplets via focused ultrasound. This provides localized emboli (i.e. gas bubbles) capable of occluding blood vessels. These droplets consist of a superheated dodecafluoropentane (DDFP) core and a stabilizing albumin shell. Endothelial cells (EC), lining of our blood vessels, are known to interact with albumin. Under certain flow conditions, these droplets could interact and stick to the EC surface making them targets for a violent vaporization process. EC were cultured in OptiCell\textsuperscript{TM} culture chambers at 37\textdegree C. Droplets at a concentration of $10^6$ droplet/mL were added and evenly distributed. Various areas were selected and exposed to different treatments comprising of a single, 8-cycle, 7.5-MHz or 3.5-MHz pulse at different acoustic pressures. Cells were fluorescently stained after the treatments to assess cell viability. An affected area was observed and compared to our controls: no treatment, ultrasound only and droplets only. Bubble clouds generated during vaporization were pressure dependent. Cell damage was induced by all treatments containing droplets and was also dose dependent. No damage was observed in any control. Damage was significant when a 3.5-MHz pulse was used at pressures above 5 MPa. All other treatments were not significant. These effects might be directly related to ADV when droplets are in direct contact with the EC. Flow conditions were not considered, but it is expected that this will change these results. Droplet configurations that have low affinity for the EC surface should be considered to avoid or minimize cell damage.

\textit{This work was funded, in part, by NIH grant R01EB006476}
Dynamic cellular contractile force response under uniaxial substrate stretch
Yue Shao¹, Jennifer M. Mann¹, Jianping Fu¹,².

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
²Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

Cellular contractile force against extracellular matrix (ECM) plays an important role in mechano-responsive cellular behaviors such as adhesion, migration and differentiation. Evidence mounts in recent years suggesting a close relationship between dynamic regulation of contractile force and cellular mechano-responsiveness. In this study, to understand how cells interpret external stimuli by modulating its dynamic intracellular contractile force, we investigated the spatiotemporal feature of such contractile force in response to uniaxial substrate stretch. To apply substrate stretch and measure cellular contractile force simultaneously, a uniaxial cell-stretching device (CSD) has been developed with vacuum-driven stretch of a PDMS basal membrane and in situ force sensor made of PDMS microposts. Device design and optimization have been first achieved by finite element simulations and then tested by experimental calibrations. Numerical and experimental results show that a uniform uniaxial substrate stretch is achieved with our CSD. Using microcontact printing to define circular cell shape, we studied how the dynamics of local contractile force is affected by the relative orientation between force and uniaxial substrate stretch. Our results showed that the orientation of local contractile force is always centripetal and stays unchanged after the substrate stretch is applied. Further, our results showed an orientation-independent dynamic response of the magnitude of local contractile force induced by uniaxial substrate stretch. To understand how uniaxial stretch is transduced into dynamic cellular contractile force independent of the relative orientation between them, a hypothetical biomechanical model is proposed based on a “mechanical network” composed of a globally interconnected actin cytoskeleton structure.

This work was funded, in part, by the National Science Foundation (NSF CBET 1149401 and NSF CMMI 1129611) and the American Heart Association (12SDG12180025).
Invariant based constitutive modeling of bat wing skin under biaxial extension
Alyssa Skulborstad\textsuperscript{1}, N. C. Goulbourne\textsuperscript{1}

\textsuperscript{1}Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Bats are unique among flying animals due to their thin, flexible, damage tolerant wing membranes which allow great extensions of the wing and multiple flight modes, including hover. To mimic these capabilities in applications such as micro-aerial vehicles, an understanding of the structure-property-function relationship of the wing membrane is needed. As a first step, our objective in this study is to develop a constitutive model based on a continuum mechanics framework to describe the mechanical response of the wing skin under a large range of biaxial loading states. The wing skin may be considered as an isotropic matrix with two families of nearly orthogonal fibers with diameters on the order of 50-100 μm; one family is oriented along the wing span direction, and one family is oriented chordwise. Biaxial extension tests are performed under displacement control protocols on a 24 mm by 24 mm skin sample and yield a series of stress-strain curves. The material behavior shows exponential dependence on the strain invariants I\textsubscript{1}, I\textsubscript{4}, and I\textsubscript{6}. Thus, the proposed strain energy function is the sum of three exponential terms in the invariants: the I\textsubscript{1} term corresponds to the isotropic matrix contribution, and the I\textsubscript{4} and I\textsubscript{6} terms correspond to the spanwise and chordwise fiber family contributions, respectively. The fitting technique uses a least squares algorithm and incorporates structural information of the skin. The proposed model is compared with the widely used Fung type model and the Holzapfel model for a tissue with two families of fibers.

This work was funded, in part, by the Air Force Office of Scientific Research (Grant #F023809), with fellowship support from the Horace Rackham Graduate School of the University of Michigan.
Nanomaterials such as surfactants and polymers used in drug delivery cause chronic cell membrane permeability

Sriram Vaidyanathan¹, Bradford G. Orr², Mark M. Banaszak Holl³

¹ Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
² Department of Physics, University of Michigan, Ann Arbor, MI
³ Program in Applied Physics, University of Michigan, Ann Arbor, MI
³ Department of Chemistry, University of Michigan, Ann Arbor, MI

Surfactants, polymers and cationic lipids are commonly used for the delivery of biomolecules such as DNA, RNA and proteins into cells. Far from being inert components, these delivery agents interact with cell organelles and induce physiological effects. For example, the cytotoxicity of gold nanoparticles has been attributed to residual amounts of the surfactant cetyl trimethylammonium bromide (CTAB) used to produce the nanoparticles. We have investigated the effect of surfactants (SDS, CTAB, and TritonX-100), polymers (Linear Polyethyleneimine and PAMAM Dendrimers), cationic lipids (DOTAP, DOTAP:DOPE) and polymer-DNA polyplexes on the membrane conductivity of HEK293A and HeLa cells. For this purpose, we used an automated whole cell patch clamp technique that can measure membrane currents from 320 cells simultaneously. We have observed that the exposure of cells to surfactants and polymers results in increased membrane conductivity even at sub-toxic concentrations. Surfactants induce increased conductivity within 1 s after exposure. This increased membrane conductivity is not reversible even 15 minutes after exposure. Experiments with the fluorescent amphiphile Octadecyl Rhodamine B suggest that the increase in conductivity is associated with the rapid intercalation of surfactants and polymers in the cell membrane. We are currently investigating the influence of membrane permeability induced by polymers on transfection efficiency. The disruption of cell membranes by the intercalation of misfolded amyloid peptides has also been suggested as a mechanism for their toxicity in Alzheimer's disease. Thus, the insights gained from this study could also be useful for understanding diseases caused by such membrane active peptides.

This work was funded, in part, by the National Institute of Health.
Biomechanical factors affecting part handling behavior: object weight

Wei Zhou¹, Thomas J. Armstrong¹, Diana M. Wegner², and Matthew P. Reed¹

¹Center for Ergonomics, University of Michigan, Ann Arbor, MI
²General Motors, Warren, MI

Posture prediction can be used to design work equipment and methods that provide workers with sufficient control over objects in object transfer tasks. This study aims to develop models for predicting probability of posture used to grasp, hold, and place work object. In a laboratory study of standing tasks, twenty subjects (10 males and 10 females) were asked to get, hold, and put cylindrical objects with weights of 3.3, 20.0, 36.7, and 53.3 N located at elbow height. Subject-selected grasping and placing postures were categorized as overhand or underhand, holding postures by height (elbow height, shoulder height, mid-thigh height) and by grasp type (underhand, vertical, hook, and palm grip). The selection of lifting, placing, and holding postures were all influenced by object weight. The probability of choosing an overhand posture to grasp cylinders was reduced from 85% to 0 as cylinder weight increased from 3.3 N to 53.3 N. Subjects held light cylinders (3.3 N) at elbow height 20% of the time, and at mid-thigh height using a hook grip 80% of the time. The probabilities of holding the cylinder at elbow height and at mid-thigh height decreased for heavier objects. Subjects held heavy cylinders (53.3 N) 60% of the time at shoulder height using a palm grip. Subjects placed cylinders using postures similar to the ones for grasping. Logistic models were proposed to predict the probability of postures and a biomechanical analysis of joint loads was conducted to evaluate hypotheses concerning the posture-selection behavior. The thresholds of joint load were determined corresponding to 50% probability of changing from one posture to alternate posture.

This work was funded, in part, by General Motors and by the partners of the Human Motion Simulation Laboratory at the University of Michigan.
Engineering in Medicine

Session Chair: Joyce Loh
Infrared fiber lasers – a new frontier in laser medicine

Vinay V. Alexander¹, Zhennan Shi¹, Mohammed N. Islam¹,²,⁴, Michael J. Welsh¹,³, Fred L. Terry, Jr.¹, Hitinder S. Gurm², Michael J. Freeman⁴

¹Department of Electrical Engineering, University of Michigan, Ann Arbor, MI
²Department of Internal Medicine, University of Michigan Medical School, Ann Arbor, MI
³Department of Cell and Developmental Biology, University of Michigan, Ann Arbor, MI
⁴Omni Sciences, Inc., Dexter, MI

Infrared laser wavelengths near ~1720 nm are of special interest in targeting lipid and/or collagen rich tissues due to the high absorption coefficient of human fat and collagen combined with low water scattering and absorption. In this poster, we present the development of a novel all-fiber laser at ~1708 nm and demonstrate its potential applications in dermatology (treatment of acne), ophthalmology (treatment of myopia) and cardiology (treatment of diabetes). The laser treatment for acne involves targeting and thermally damaging the lipid-rich sebaceous glands in human skin, responsible for acne. The laser treatment for myopia involves thermally modifying the collagen content in the cornea (collagen is the major constituent of the cornea after water). This thermal interaction causes the collagen structure to shrink and ultimately change the shape of the cornea, thus, affecting the refractive power of the eye. In the final application, as a potential treatment for diabetes, we show that our laser can selectively target and damage the visceral fat in the abdominal region without damaging the surrounding tissue and blood vessels. Visceral fat has been associated with insulin sensitivity, diabetes and metabolic disorders. In the applications presented here, we utilize the laser wavelength selectivity to target the tissue of interest and, therefore, avoid most, if not all of the collateral damage to the surrounding tissues. Thus, the preliminary in-vitro results presented here show the ~1708 nm laser as a promising tool with a wide variety of real world medical applications.

This work was funded, in part, by Cardiovascular Center at the University of Michigan and by Omni Sciences, Inc.
Fluorescent BP retention in mouse mandible under altered bone turnover conditions
Adrienne F. Alimasa$^{1,2}$, Joseph E. Perosky$^2$, Emilee L. Borgmeier$^2$, Laurie K. McCauley$^3$, Kenneth M. Kozloff$^{2,1}$

$^1$Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
$^2$Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, MI
$^3$Department of Periodontics and Oral Medicine, University of Michigan, Ann Arbor, MI

Osteonecrosis of the jaw (ONJ) is defined as a condition of exposed bone in the oral cavity that persists for at least 8 weeks in patients without history of past radiation therapy. While ONJ has been associated with bisphosphonate (BP) use, it remains unknown whether BPs play a causal role in ONJ. The jaw may prove to be a skeletal site of increased BP concentration, resulting in susceptibility to the effects of BPs. Using a fluorescent far-red pamidronate (FRFP) imaging technique, prior experiments in mice demonstrated elevated BP delivery in the mandible compared to the femur and tibia regardless of bone turnover status. The same imaging method was employed to explore the mandible as a skeletal site of increased BP retention. Following one FRFP dose, high and low bone turnover were induced by parathyroid hormone and pamidronate treatments, respectively. A control group was treated with phosphate buffered solution. FRFP signal retention was quantified using fluorescence imaging at a baseline time and at treatment termination. Bone formation rate per bone surface was calculated using dynamic histomorphometry. FRFP was significantly retained in the mandible compared to the femur and tibia under all conditions of bone turnover. Dynamic histomorphometry revealed that parathyroid hormone and pamidronate induced changes in the femur and tibia. However, no significant effect on bone turnover was observed in the mandible. These studies suggest the mouse mandible is susceptible to higher BP concentrations despite bone turnover conditions.

This work was funded, in part, by NIH R21 DE19812-01.
Ultra low-power filter bank for hearing aid speech processor
Mahmood Barangi¹, Jaeyoung Kim¹, Pinaki Mazumder¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

In this work we developed an ultra-low power filter bank in TSMC 65nm process. We demonstrate that a 16 channel FIR filter bank with built-in 2-Kb Static Random Access Memory (SRAM) consumes merely 600 pJ per FIR operation while operating at 1 MHz clock frequency in subthreshold mode with a 300 mV power supply. The design uses unit sharing technique and exploits the low performance of hearing aid systems to reduce power supply and go deeper in sub-threshold operation. A 2-kb custom SRAM has been incorporated to interface with the system while maintaining memory robustness at sub-threshold operation. At 0.3V supply voltage, the designed 10-T SRAM cell shows 60 mV higher noise margin, 95% less BER, and 50% less read leakage compared to the conventional 6-T design. The designed filter bank has a non-uniform frequency response. A uniform filter bank makes the filter design simpler at the expense of gain stage complexity and thereby larger silicon area. The filters are 109th order Chebyshev window digital filters to make sure that the second lobe is at best below -60 dB amplitude. By characterizing the standard cells for sub-threshold operation, we managed to run the system with clock frequencies up to 12 MHz at 0.3 V supply voltage. The characterization approach provides 24% higher throughput than conventional synthesis with only 1.5% power tradeoff.

This work was partially done under the DARPA/AFOSR grant FA9550-12-1-0033
UV degradation of acetal-modified dextran electrosprayed-fabricated particles

Tae-Hong Park¹, Thomas W. Eyster, Joshua M. Lumley, Sangyeul Hwang, Kyung Jin Lee, Asish Misara, Sahar Rahmani, Joerg Lahann

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

Microparticles for drug delivery have emerged as a key technology in medicine. Characteristics such as toxicity, biodegradability, and mechanism of drug release are important parameters in any drug system and must be designed carefully. Here, we present an acetalated dextran (Ac-Dex) particle for chemotherapeutic delivery. Electrohydrodynamic jetting ('electrospraying') was our method of choice for particle generation due to the relatively monodisperse results and ease of adding drugs and photoacids to the polymer solution before jetting, obviating the need for complicated material chemistries to encapsulate our chemotherapeutic. Ac-dex is insoluble in water unlike dextran, but in order to stimulate drug release, we have included a photoacid generator. Upon application of UV light, the photoacid deprotects the Ac-Dex, leading to dextran particles which rapidly dissolve in water and release the desired drug. We confirmed that our protocol for synthesizing Ac-Dex works using ¹H NMR, and then demonstrated particle degradation via UV-light activation of our photoacid. Particles without the photoacid remained particles despite application of UV light, while particles containing the photoacid degraded within 20 minutes. ¹H NMR confirms the deprotection of acetal groups in Ac-Dex particles exposed to UV light. The release profile of our particles was studied by loading the particles with the fluorescent payload rhodamine-B PEG. Finally, we demonstrate that our particles can release our chemotherapeutic (irinotecan) upon UV light stimulation, effectively killing our in vitro colon cancer cell line model (HT-29).
Physiological imaging-defined response-driven subvolumes of a tumor

Reza Farjam, M.S.E\textsuperscript{1,2}, Christina I. Tsien, M.D.\textsuperscript{2}, Felix Y. Feng, M.D.\textsuperscript{2}, Diana Gomez-Hassan, M.D., Ph.D\textsuperscript{3}, James A. Hayman, M.D.\textsuperscript{2}, Theodore S. Lawrence, M.D., Ph.D.\textsuperscript{2}, and Yue Cao, Ph.D.\textsuperscript{1,2,3}

\textsuperscript{1}Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Radiation Oncology, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Department of Radiology, University of Michigan, Ann Arbor, MI

Dose painting of the physiological response-driven subvolumes of a tumor could have a better outcome in radiotherapy than distributing a uniform dose within a target volume defined by anatomical imaging. Hence, we aim to develop an imaging technology to delineate the response-driven subvolumes of a tumor based upon its heterogeneous underlying physiology. We assign each tumor voxel a physiology-based probability function based on which we delineate the subvolumes of a tumor. We applied our approach to regional cerebral blood volume (rCBV) and Gd-DTAP transfer constant ($K_{\text{trans}}$) images of patients (45 lesions in total) who had brain metastases and were treated by whole brain radiotherapy (WBRT). Changes in rCBV/$K_{\text{trans}}$-defined subvolumes of the tumors from pre-RT to 2 weeks (2W) after the start of WBRT were evaluated for differentiation of responsive, stable and progressive tumors using Mann-Whitney $U$ test. Performance of the newly developed metrics for predicting tumor response to WBRT was evaluated by Receiver Operating Characteristic (ROC) analysis. We found that decrease in the high-CBV defined subvolumes of the tumors from pre-RT to 2W was significantly greater in the group of responsive tumors than the group of stable and progressive ones ($p<0.007$). The change in the high-CBV defined subvolumes of the tumors from pre-RT to 2W was a predictor for post-RT response significantly better than the change in gross tumor volume observed during the same time interval ($p=0.0124$), suggesting the physiological change occurs prior to the volumetric change. Also, $K_{\text{trans}}$ did not add significant discriminatory information to rCBV for response assessment.

\textit{This work is supported in part by NIH grants RO1 NS064973 and R21 CA113699}
Signal transduction and acquisition using the regenerative peripheral nerve interface

Theodore A. Kung¹, John V. Larson¹, Jana D. Moon¹, Nicholas B. Langhals¹, Melanie G. Urbanchek¹, Paul S. Cederna¹

¹Department of Surgery Section of Plastic Surgery, University of Michigan, Ann Arbor, MI

Intro: The regenerative peripheral nerve interface (RPNI) consists of a unit of free muscle that has been neurotized by a transected peripheral nerve. In conjunction with a biocompatible electrode, RPNI technology offer enormous potential for amputees by facilitating signal transduction from the residual peripheral nerve to a neuroprosthetic limb. Moreover, the RPNI allows for both high-fidelity motor function and sensory feedback. Methods: Free muscle is transferred to the site of peripheral nerve transection and the residual proximal nerve segment is used to neurotize the muscle. A stainless steel pad electrode, with or without electroconductive polymer, is affixed to the epimysial surface of the transferred muscle and the entire construct is wrapped in xenogeneic small intestinal submucosa extracellular matrix (Surgisis, Cook). Serial percutaneous nerve conduction studies demonstrate evidence of muscle reinnervation and signal transduction through the biotic-abiotic interface. Histologic examination also confirms muscle reinnervation and minimal encapsulation of the electrode. Results: The use of free muscle controls neuroma formation, amplifies biologic signal, and functions as a shock-absorber between delicate nervous tissue and rigid electrode. Xenogeneic small intestinal submucosa extracellular matrix provides a porous outer layer which serves to contain the interface while also facilitating revascularization of the transferred muscle through plasmatic imbibition and revascularization. Furthermore, scar maturation of the Surgisis may result in signal isolation between adjacent electrodes, further enhancing high-quality signals. Axonal regeneration and formation of new neuromuscular junctions results in electrical continuity between the host tissue and implanted electrodes. Conclusion: Continued development of RPNI technology will facilitate high-fidelity volitional operation of bioengineered neuroprostheses. Future work is focused on signal processing of multi-channel arrays and signal isolation using advanced biomaterials.

This work was supported by the DARPA RPI program under grant N6601-11-C-4190 and by the Plastic Surgery Foundation.
Electrophysiological evaluation of epimysial thin-film polyimide arrays
John V. Larson¹, Theodore A. Kung¹, Melanie G. Urbanchek¹, Paul S. Cederna¹, Nicholas B. Langhals¹

¹Department of Surgery Section of Plastic Surgery, University of Michigan, Ann Arbor, MI

Background: The field of neuroprosthetics holds the promise of restoring extremity function after limb amputation. Paramount to this goal is the development of a reliable, high fidelity signal interface which connects the prosthesis to residual tissue. The objective of this study was to assess the electrophysiological properties of flexible polyimide arrays when applied to muscle. Methods: Flexible thin-film polyimide-based electrode arrays (NeuroNexus Technologies, Ann Arbor, MI) were developed for this study. The array contains 32 microelectrodes embedded within 15 μm thick polyimide. Normal F344 rats (n = 6) were anesthetized, and the common peroneal nerve and extensor digitorum longus (EDL) muscle were exposed. The array was affixed to the epimysium of the EDL muscle and a stimulating electrode was placed on the peroneal nerve to induce activity. Electromyographic studies were then performed and analyzed to evaluate recording performance metrics. Results: Successful recordings were obtained in 97.4% of the 32 channels. The average threshold electrical stimulation for eliciting a Compound Muscle Action Potential (CMAP) was 114.17 µA (range, 47-225; SD, 56.10), which resulted in an average CMAP peak-to-peak amplitude of 17.23 mV (range, 0.75-24.81; SD 7.41) at an average latency of 3.56 ms (range, 2.62-5.03; SD 0.76). Conclusion: Within this study, flexible polyimide electrodes successfully recorded high fidelity, low variability muscle signals. This data and confirmed functionality validates their role for use in bio-artificial interfaces.

This work was supported by the DoD MURI program under grant W911NF-06-1-0218, by the DARPA RPI program under grant N6601-11-C-4190, and by the Plastic Surgery Foundation.
Reliability of sensation measurement by von frey filaments in the rat
Andrej Nedic¹, TA Kung², JD Moon², NB Langhals², PS Cederna², MG Urbanchek²,

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²Department of Plastic Surgery, University of Michigan, Ann Arbor, MI

Tools that quantify sensation are essential in research and clinical assessment of closed loop sensory receptor, nerve, and central nervous system function. One simple tool used in both environments is von Frey filament testing. Though von Frey test reliability values are published, reliability for testing in the rat at various locations is not available. Our purpose was to determine the reliability of von Frey (VF) filament sensation measurement in the rat. Select VF filaments apply known force when pressed on skin. VF testing was applied to normal rats (n = 6), at two anatomical locations, in an up-down pattern, (Dixon 1985) three times per testing session over a span of six weeks. Withdraw threshold was determined by monitoring response patterns while alternately exceeding and reducing filament pressure based on the previous response. The ideal filament range was 0.03 g—3.63 g at the ankle and 0.17 g—8.51 g at the thigh. By converting sensation threshold to log scale values, data fit normal distributions. Mean sensation thresholds were different between the ankle and thigh. Responses across three trials were not statistically different. During the six week testing period, responses did not vary over time. A learning effect was not recognized statistically. Subsequent von Frey testing of skin with nerve injuries showed the animals were less sensitive than the normal group.

This work was supported by the DARPA RPI program under grant N6601-11-C-4190.
Evaluation of rod-shaped carriers for vascular imaging and targeted drug delivery in large vessels
Alex J. Thompson¹, Katawut Namdee¹, Diane Bouïs², and Omolola Eniola-Adefeso¹

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
²Cardiovascular Center, University of Michigan, Ann Arbor, MI

The development of vascular-targeted carriers (VTC) for the delivery of therapeutics could greatly improve the treatment of many diseases. Spherical nanoparticles are commonly used as potential drug carriers due to their ability to easily navigate microvasculature and ease of fabrication. Recent literature has shown that spherical nanoparticles do not efficiently marginate to the vascular wall in medium/large blood vessels (M/LBV) compared to microparticles. Therefore spherical nanoparticles may not be effective in treating diseases which occur in M/LBV, such as atherosclerosis. Recently, particle shape has received attention as a parameter that can be used to improve the performance of VTCs. The purpose of this study is to examine the hemodynamics of rod-shaped particles of different aspect ratios relative to spheres of equal volume both in vitro in human blood flow and in vivo in atherosclerotic mice. With in vitro assays we find that rod-shaped particles with equivalent spherical diameter, ESD >2 μm have a higher binding efficiency to a HUVEC monolayer from blood flow than equivalent spheres. Interestingly, there appears to be a minimum major axis length requirement for rods with ESD <2μm to display a significant increase in flow adhesion over their equivalent spheres. For in vivo assays, 2 μm spheres showed higher adhesion to plaque surface in the aorta over 0.5 μm spheres in agreement with previous in vitro studies. Ellipsoidal particles with aspect ratio (AR) 4 yielded higher adhesion in the aorta than 2 μm spheres, especially at the branch and bifurcation areas where plaque were preferentially deposited.

This work was funded, in part, by the AHA and NSF CAREER Grant.
Development of nanodroplets for targeted ultrasound-mediated ablation of cancer

Yasemin Yuksel Durmaz¹, Eli Vlaisavljevich¹, Zhen Xu¹ and Mohamed E. H. ElSayed¹, ²

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²Macromolecular Science & Engineering Program, University of Michigan, Ann Arbor, MI

We report the development of nanodroplets for targeted ultrasound (US) ablation of cancer cells. These nanodroplets (100-400 nm) contain an US contrast agent (perfluoropentane, PFP) core encapsulated in a novel polymer shell composed of a hydrophilic PEG block, a central functionalized block, and a PFP-miscible block to form stable nanodroplets. The functional groups in the central block are cross-linked to “stitch” the polymer chains together forming a flexible polymer shell that displays a “brush” of hydrophilic PEG chains. We hypothesize that nanodroplets can diffuse across tumor’s leaky vasculature and localize in tumor lesions. Applying microsecond-long US pulses to the tumor will convert these nanodroplets to microbubbles at significantly reduced pressure that will expand to a diameter ≥ 50µm before energetically collapsing and fractionating nearby cancer cells. The peak negative pressure thresholds, required to expand a PFP-loaded nanodroplet with a diameter of 100-500 nm to reach 50µm in soft tissue at 0.2, 0.5, and 1.1 MHz, were simulated. Simulation shows that the pressure threshold at lower US frequency (≤0.5MHz) was significantly decreased in comparison to the threshold in the absence of the nano-droplets. To validate the simulation results, we applied a 1-cycle long US pulse using a 500 kHz focused transducer to the RBC gel phantoms containing PFP-loaded micelles, “empty” micelles, and saline. The results show that the threshold for microbubble formation and expansion (cavitation) and cell fractionation with these nanodroplets is significantly reduced using lower frequency ultrasound pulses. By using an appropriate acoustic pressure that exceeds the cavitation threshold for cancer tissue containing nanodroplets while below the cavitation threshold for normal tissue without nanodroplets, targeted ultrasound ablation for cancer can be achieved.

This work was funded by UM Prostate Cancer SPORE and DOD-Prostate Cancer Research Program.
A three-compartment modeling and cooperativity investigation of levodopa treatment for Parkinson’s disease
Quan Zhou¹, Maya Kalyan¹, Abeer Khurram¹

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

Parkinson’s Disease (PD) is caused by the progressive death of dopaminergic neurons in the substantia nigra pars compacta (SNc). The development of this mathematical model concerned specifically with L-dopa/carbidopa treatment and investigated the therapeutic effects of the drug L-dopa in a specific brain region, SNc. Our model was built on the principles of compartment modeling but is more holistic than previous two-compartment models in that it considered molecular details of ligand binding and connects them to the system level where the reaction of the patient can be observed. Three compartments: a central compartment (bloodstream) and two peripheral compartments (the brain and the SNc) were modeled, which examines the occupancy of dopamine receptors in the SNc and explores the effects of occupancy on the reaction time of the patient. The input function, which accounts for age, allows us to define the dosing regimen for individual patients. Results were calculated for a patient of age 53. The input function also allows us to define treatment regimen. Whether the treatment is short or long, with or without maintenance dose, our model can predict results for the patient. We examined short-term and long-term effects with different input functions. We have also demonstrated that cooperativity in term of ligand binding (probability of binding based on concentration, chemical potential, and the Boltzmann distribution) plays a large role in increase of dopamine concentration in the SNc, especially for sinusoidal periodic treatments where the occupancy of receptors may increase by up to 50%.
Fluid Dynamics, Thermodynamics, Heat Transfer and Combustion

Session Chair: Brandon Patterson
A computational study of non-premixed flame extinction by water spray
P. G. Arias\textsuperscript{1}, H. G. Im\textsuperscript{1}, P. Narayanan\textsuperscript{2}, A. Trouvé\textsuperscript{3}

\textsuperscript{1}Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}National Energy Research Scientific Computing Center, Oakland, CA
\textsuperscript{3}Department of Fire Protection Engineering, University of Maryland, College Park, MD

The interaction of turbulent nonpremixed flames with fine water spray is studied using direct numerical simulations (DNS) with detailed chemistry. The study is of practical importance in fire safety devices that operate in the mist regime, as well as in their use as an inexpensive temperature control mechanism for gas turbines. Dynamics of water spray is represented by the Lagrangian particle-in-cell method, coupled with an Eulerian gas-phase reacting flow solver. The model configuration is a two dimensional ethylene-air counterflow diffusion flame at moderate strain rates. Laminar and turbulent flame simulations are performed with various water loading conditions. Comparison of various simulation cases highlights the flame weakening characteristics due to aerodynamic strain and water spray evaporation. Local flame extinction is identified for a flame weakness factor derived based on an asymptotic model under non-adiabatic environments. A statistical analysis of the cumulative turbulent flame data show that a large heat release enhancement is observed during the flame quenching due to the occurrence of edge flames, while such effects are substantially reduced in the presence of water spray. Findings from this study provide a better understanding of interaction between thermal and aerodynamic quenching in turbulent flame dynamics.
Error estimation and p-adaptation in hybridizable and embedded discontinuous galerkin methods
Johann P. S. Dahm¹, Peter N. Klein¹, Krzysztof J. Fidkowski¹

¹Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

We present a comparison of output-based error estimation and adaptation for recently developed hybridizable and embedded discontinuous Galerkin (DG) methods. Both hybridizable DG (HDG) and embedded DG (EDG) significantly reduce the number of globally coupled degrees of freedom compared to conventional DG, and differ only in the approximation space used for the numerical trace. Each retains the stability advantages and refinement (hp) flexibility enjoyed by DG. The methods are applied to a model multidimensional linear advection problem and are implemented in a shared p-adaptive framework to allow for comparison of the adaptation strategies. Order (p) adaptation is used to refine the solution, where regions of the primal and numerical trace are targeted based on an estimate of the local error magnitude. The error is estimated using an adjoint-weighted residual and a discrete fine-space adjoint approximation. Results show that adaptation reduces the error in the output for the same number of degrees of freedom. Numerical results demonstrate HDG and EDG can be combined with existing error estimation and adaptation strategies to improve robustness and accelerate convergence.

This work was funded, in part, by the Air Force Office of Scientific Research and the Department of Aerospace Engineering at the University of Michigan.
Molecular modeling diffusion of hydrocarbons
Tyler Dillstrom¹, Paolo Elvati¹, Angela Violi¹

¹Department of Mechanical Engineering, University of Michigan at Ann Arbor

Transport Properties such as viscosity, thermal conductivity, and diffusion play critical roles in combustion processes. Flame profile shapes, flame velocities, flame extinction, and pollutant product formation are all significantly affected by transport properties. It has been shown that 10% inaccuracy in transport predictions can lead to order of magnitude errors in models. Traditionally, transport properties used in combustion modeling were derived from gas kinetic theory (GKT) using classical mechanics of hard sphere collisions. However, GKT accuracy wanes significantly as molecular structure deviates from spherical. In order to develop more accurate diffusion predictions for modeling purposes, we utilized LAMMPS molecular dynamics (MD) simulations to calculate the diffusivity of several hydrocarbons in nitrogen environments. Understanding that MD calculations can be a prohibitive computational expense, we are exploring geometrical factors which could be used to create a correction to GKT formulae.
An accelerated multi-zone engine simulation model (AMES-HCCI) for HCCI combustion prediction in system level codes

Janardhan Kodavasal\textsuperscript{1}, Matthew McNenly\textsuperscript{2}, Aris Babajimopoulos\textsuperscript{3}, Mark Havstad\textsuperscript{2}, Salvador Aceves\textsuperscript{2}, Dennis Assanis\textsuperscript{3}, Daniel Flowers\textsuperscript{2}.

\textsuperscript{1}Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Lawrence Livermore National Laboratory, Livermore, CA
\textsuperscript{3}Department of Mechanical Engineering, Stony Brook University, Stony Brook, NY

We have developed an Accelerated Multi-zone Engine Simulation model for Homogeneous Charge Compression Ignition (HCCI) combustion modeling (AMES-HCCI). This model incorporates chemical kinetics and is intended for use in system level codes. A novel methodology to capture thermal stratification in the multi-zone model is proposed. The methodology calculates thermal stratification inside the cylinder based on a single Computational Fluid Dynamics (CFD) simulation for motored conditions. CFD results are used for deriving zone heat loss multipliers that characterize wall heat loss from each individual engine zone, in the belief that these heat loss multipliers can then be used at diverse operating conditions far removed from those used in the single CFD run. This is because thermal stratification is a stronger function of engine geometry than operating conditions. The model was benchmarked against detailed CFD calculations and fully coupled HCCI CFD-chemical kinetics calculations. The results indicate that the thermal stratification methodology accurately captures thermal stratification developed through the compression stroke and (therefore) HCCI combustion. The AMES-HCCI model with the thermal stratification methodology and gasoline kinetics shows good agreement with boosted gasoline HCCI experiments over a range of operating conditions, in terms of in-cylinder pressure and heat release rate predictions. This model eliminates expensive fluid mechanics calculations which results in up to two orders of magnitude speed-up compared to CFD, which makes the method very well suited for rapid HCCI calculations in system level codes such as GT-Power, where it is often desirable to simulate consecutive engine cycles.

\textit{This work was funded, by the Department of Energy, Office of Vehicle Technologies, Gurpreet Singh, Technology Development Manager.}
A study of the entrainment and mixing in confined turbulent jets used for industrial combustion
I. S. Lee\textsuperscript{1} and A. Atreya\textsuperscript{1}

\textsuperscript{1}Department of Mechanical Engineering, University of Michigan at Ann Arbor

Confined reacting turbulent jets are widely employed in industrial furnaces. The flame patterns and emissions of confined turbulent jet flames are influenced on the jet interaction and mixing. This paper presents the results of an experimental and numerical investigation of mixing characteristics and the resulting chemical composition in a confined, non-reacting turbulent jet. This is a first step toward understanding confined reacting jets. The experiments are designed to simulate exhaust flow as co-flow from 1 to 10 MMBtu industrial-scale burners. The apparatus consists of: (i) a 2ft diameter 6ft long cylindrical vertical exhaust duct that carries 328.15K slight hot air at co-flow velocities ranging from 0.11 to 1.11 m/s, (ii) ambient temperature high velocity air jet containing a NO tracer gas is injected by a ¼ inch nozzle in the center of the vertical duct. Temperature, composition, and velocity profile measurements are made along the length of the jet to determine the extent of entrainment and the dilution of the jet fluid as a function of the co-flow and jet flow velocities. These measurements will help determine the diameter of the collection duct and its distance from the injection nozzle. Numerical calculations using FLUENT are conducted to determine the details of the flow field. These calculations essentially confirm the experimental results and provide a picture of the flow field. These results provide fundamental information on entrainment in confined jets used in industry.
Predictive models for the formation of nanoparticles at high temperatures
Jeffrey Lowe¹, Angela Violi¹,²,³,⁴,⁵, Paolo Elvati³

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
²Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
³Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
⁴Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI
⁵Department of Applied Physics, University of Michigan, Ann Arbor, MI

Transportation is responsible for the second largest portion of energy use in the US. In order to provide the scientific foundation to enable technology breakthroughs in transportation fuel, it is important to develop a combustion modeling capability to optimize the operation and eventually design of evolving fuels in advanced engines for transportation application. Within this framework, the work proposed by our group aims at developing a validated predictive model to describe the formation of nanoparticles from various fuels in high temperature conditions. This predictive capability, if attained, will change fundamentally the modeling of soot formation by establishing a scientific understanding of sufficient depth and flexibility to facilitate realistic simulation of fuel combustion and particle formation in more complex systems, such as existing and proposed engines. The majority of numerical studies that describe particle formation invoke the dimerization of pyrene molecules as the initial nucleation step for the formation of particles. From thermodynamic considerations, however, the condensed-phase would evaporate at flame temperature, rather than vapor-phase condensing into particles. In this work, we determine the free energy associated with the dimerization of various polycyclic-aromatic hydrocarbons (PAH) using molecular dynamics simulations. Our results show that the aliphatic-substituted PAH, rather than pyrene, play an important role in the formation of dimers, with saturated chains having a more marked effect than unsaturated groups. Computational modeling of engines will accelerate the improvement of existing energy technologies and the development of new transformational technologies by pre-selecting the designs most likely to be successful for experimental validation. This research was funded by the Department of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, Geosciences, and Biosciences under Contract No. DE-SC0002619.
Transient thermal control of electronics using phase change materials
Sashwat Mahapatra¹, M. Cheralathan², R. Velraj³

¹Department of Atmospheric and Oceanic Space Sciences, University of Michigan, Ann Arbor, MI
²Department of Mechanical Engineering, SRM University, Chennai, India
³Institute of Energy Studies, Anna University, Chennai, India

The need for highly efficient heat sinks has become indisputable due to recent technological advancements in the electronic devices industry. Devices with low duty cycles, such as those that are not operated continuously over long periods of time, have the advantage of having a significant portion of time for cooling. Therefore a phase change material (PCM)-based cooling system is highly suitable for such applications. The present method identifies and quantifies the PCM to be used so as to achieve efficient thermal control by extracting maximum heat energy from the source in the least time possible and in the least area available. Amongst the commercially available PCMs, Lauric acid displays the most effective thermal control by stabilizing the chip surface temperature to workable limits. On enhancing the thermal conductivity of PCM by using Cu Nano particles the final chip surface temperature is further reduced by 15 °C bringing it within the desired working limits. This technique is advantageous as there is no initial energy input into the system and has significant applications in space craft electronics where duty cycles are low and heat energy needs to be stored for later usage during the eclipse period.
Theoretical microbubble dynamics in a viscoelastic medium at capillary breaching thresholds
B. Patterson¹, D.L. Miller², E. Johnsen¹.

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
²Department of Radiology, University of Michigan, Ann Arbor, MI

In order to predict bioeffects in contrast-enhanced diagnostic and therapeutic ultrasound procedures, the dynamics of cavitation microbubbles in viscoelastic media must be determined. For this theoretical study, measured 1.5-7.5 MHz pulse pressure waveforms, which were used in experimental determinations of capillary breaching thresholds for contrast-enhanced diagnostic ultrasound in rat kidney, were used to calculate cavitation nucleated from contrast agent microbubbles. A numerical model for cavitation in tissue was developed based on the Keller-Miksis equation (a compressible extension of the Rayleigh-Plesset equation for spherical bubble dynamics), with various viscoelastic constitutive relations (Kelvin-Voigt, Maxwell, and Standard Linear Solid). From this model, the bubble dynamics corresponding to the experimentally obtained capillary breaching thresholds were determined. Values of the maximum radius and temperature corresponding to previously determined bioeffect thresholds were computed for a range of ultrasound pulses and bubble sizes for comparison to inertial cavitation threshold criteria. The results were dependent on frequency, the filling gas, and the tissue elastic properties. The bioeffects thresholds were above previously determined inertial cavitation thresholds, even for the tissue models, suggesting the possibility of a more complex dosimetry for capillary injury in tissue.
One-dimensional numerical simulations of shockwave interaction with a visco-elastic medium
Mauro Rodriguez ¹, Eric Johnsen ¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

Understanding the mechanics and dynamics of shockwaves within isolated cavitation bubbles in soft tissue is very important to many prospective and developing medical applications. As an example, histotripsy is a non-invasive ultrasonic tissue ablation therapy tool currently being developed by the Therapeutic Ultrasound Group from the Biomedical Engineering Department at the University of Michigan. Histotripsy utilizes ultrasound waves to generate clouds of cavitation bubbles that due to the oscillations and collapse of said bubbles for an expected fine precision tissue destruction. This technology has the prospect of being used for treating prostate and breast cancer. However, the mechanism of the bubble clouds growth and its shockwave effects are still unknown. Thus, this work focuses on using numerical methods to understand shockwave propagation within a viscoelastic medium. Using numerical methods along with shock-capturing schemes to simulate this type of propagation has its challenges as modeling the viscoelastic medium involves introducing stress rate and strain terms. The traditional stress and strain rate terms are also used but can be solved using finite differencing methods. The stress rate and strain terms, however, present unique challenges as finite differencing methods cannot be easily employed for these terms. The research presents a one-dimensional analysis that treats the stress terms solely as Newtonian stress terms and solves for them using two different numerical algorithms. The work also introduces early results for solving for the stress terms utilizing the visco-elastic Voigt model.
Internal combustion engine exhaust gas recirculation cooler fouling
Ashwin Salvi\textsuperscript{1}, John Hoard\textsuperscript{1}, Dan Styles\textsuperscript{2}

\textsuperscript{1}Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Ford Motor Company, Dearborn, MI

The use of exhaust gas recirculation (EGR) in internal combustion engines has significant impacts on combustion and emissions. EGR can be used to reduce in-cylinder NOX production, emitted particulate matter, and enable advanced forms of combustion. To maximize the benefits of EGR, the exhaust gases are often cooled with on-engine liquid to gas heat exchangers. A common problem with this approach is the build-up of a fouling layer inside the heat exchanger due to thermophoresis and condensation, reducing the effectiveness of the heat exchanger in lowering gas temperatures. Literature has shown the effectiveness to initially drop rapidly and then approach steady state after a variable amount of time. The asymptotic behavior of the effectiveness has not been well explained. A range of theories have been proposed including fouling layer removal, changing fouling layer properties, and cessation of thermophoresis. In an effort to investigate this phenomenon, an EGR cooler visualization rig has been constructed. This rig incorporates an optically and infrared transparent access window, allowing for measurement of key deposit layer variables in-situ. These variables coupled with heat flux measurements will allow for the calculation of thermal properties of the deposit layer as a function of time, engine condition, and emissions levels. This poster will describe the visualization rig, methodology for in-situ measurements, and initial results.
IOE and Financial Engineering

Session Chair: Denny Yu
The credits that count: credit and risk in the student loan market
Katharina Best\textsuperscript{1}, Jussi Keppo\textsuperscript{2}

\textsuperscript{1}Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Economics, Aalto University, Helsinki, Finland

Using a two-stage least squares model, we build a macroeconomic model of supply and demand for US higher education. We find that credit factors (e.g. student loan amounts and household debt) are primary drivers of demand, along with college education benefits (e.g. relative earnings and employment level). Tuition prices and debt levels are highly correlated, suggesting that students respond to higher tuition prices by borrowing. Further, we construct a survival-based model of student loan defaults to estimate default probabilities for different types of students. We allow for frailty-correlation based on unobserved risk factors, responses to macroeconomic conditions, and student characteristics.
Dynamic pricing with strategic customers under price adjustment policy
Beryl Boxiao Chen¹, Xiuli Chao¹, Hyun-Soo Ahn².

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
²Ross School of Business, University of Michigan, Ann Arbor, MI

We study the dynamic pricing strategy of a monopolist serving heterogeneous forward-looking customers. The firm offers a price adjustment policy, which guarantees current buyers a full refund of the difference if they find a lower future price within a certain time window. We establish the existence of a subgame perfect equilibrium pricing policy and show that the firm sets different equilibrium pricing patterns in different regions of system parameters. Finally we investigate the effect of introducing the price adjustment policy to the firm as well as to the customers.
The human hand is used for nearly all human-activities to manipulate work objects and to support the body. Failure to maintain sufficient control over the work object can result in acute injury of the hand or other body parts. In addition, repetitive exertion of the hand can result in musculoskeletal pain and injury. Chronic and acute injuries involving the hand are a major cause of injury and disability. This work aims to develop biomechanical models that can be used to study and prevent both acute and chronic injuries associated with hand use. Previous studies demonstrate the important value of biomechanical hand models for equipment design, safety, clinical and robotic applications. So far the application of these models has been quite limited due to specific anatomical information for each hand. New knowledge is needed that can be used to apply these models to individuals or specific populations for specific tasks. We propose to develop a model that: 1) can be used to predict link lengths, tendon moment arms based on external dimensions using regression and principle components analysis. 2) Will be scalable with parameters based on hand length and handbreadth for female and male measurements in order to cover a vast percent of the worker’s population. CT-Scan images will be used to develop scalable 3D hand anatomical representations based on the bones and skin for the model's skeletal system. This part of the project aims to validate and explain the process of determining the anatomical joint centers and cartilage distances.
An IP-based Handoff-sensitive shift design approach for scheduling critical care trainees

Pooyan Kazemian¹, Yue Dong², Thomas R. Rohleder³, Jonathan E. Helm¹, Mark P. Van Oyen¹.

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
²Multidisciplinary Simulation Center, College of Medicine, Mayo Clinic, Rochester, MN
³Center for the Science of Health Care Delivery, Mayo Clinic, Rochester, MN

Recent ACGME duty-hour limits were intended to reduce fatigue-related medical errors. However, the resulting shorter shifts are associated with more frequent handoffs that correlate with adverse events. We employ optimization (integer programming) to develop on-call schedules for ICU residents/fellows that comply with ACGME regulations, provide 24/7 ICU coverage, and satisfy livability constraints with as few patient handoffs as possible. Implementation in a hospital setting is discussed.

This work was funded in part by the Center for the Science of Health Care Delivery at Mayo Clinic, Rochester, Minnesota.
Optimization-based approach in solar cell embedded distribution grid power control

Xing Li

1Industrial & Operations Engineering, University of Michigan, Ann Arbor, MI

We present an optimization-based model for power control in a local distribution grid with emerging solar cells embedment in houses. Models are formulated. The problem is simulated and solved based on real data and environment. Optimal algorithms and solution benchmark are discussed. The potential implementation of the modeling framework at the local grid is also outlined.
Beam orientation optimization in radiation therapy treatment planning
Troy Long¹, Edwin Romeijn¹

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI

The purpose of our work is to efficiently select high-quality coplanar or non-coplanar beam orientations for IMRT treatments while formally and explicitly incorporating the effect of the selected beam orientations on the quality of the dose distribution obtained by the treatment plan optimization model. Beam orientation models consider a discrete set of potential coplanar and/or non-coplanar beam locations around the patient. A new greedy algorithm is proposed to solve a model that integrates beam orientation optimization (BOO) and fluence map optimization (FMO). The algorithm iteratively adds beams to a FMO model. In each iteration, an attractiveness measure is associated with each remaining candidate beam orientation. This attractiveness measure is based explicitly on an optimal dose distribution that allows only the currently selected set of beams to be used. Several alternate attractiveness measures are considered which use either first-order information or both first and second-order information. Performance of the algorithm was assessed on a clinical cancer case.
The effects of display clutter on pilot attention and performance in a simulated flight scenario
Nadine Moacdieh¹, Nadine Sarter¹

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI

Clutter is a problem that affects operators in complex, data-rich environments. For example, in airplane cockpits, clutter in primary flight displays (PFDs) can prevent pilots from rapidly and accurately detecting important information. In this study, our goals were to provide guidance for the design and evaluation of PFDs, develop eye tracking-based assessment tools that can detect the attentional costs associated with clutter, and establish the link between clutter in PFDs, pilot attention, and pilot performance. To this end, we developed a flight simulator that represents a generic glass cockpit. Two PFD designs (low and medium clutter) were created, with a high-clutter PFD currently in progress. 15 instrument-rated airplane pilots flew a 32-minute flight scenario that was divided into two periods of high workload (takeoff and approach) and a period of low workload (cruise). Throughout the flight, alerts and notifications appeared that pilots had to acknowledge by pressing a response button. Half of the alerts were knowledge-driven; i.e., they were shown to pilots during the training session. The rest of the alerts were data-driven (i.e., not previewed) and expected to capture attention in bottom-up fashion. Clutter was varied as a between-subjects variable such that pilots used either a low or a medium-clutter PFD. After completing the scenario, pilots filled out a debriefing questionnaire. Results showed that response time and error rate were higher in the case of medium clutter, especially during high workload. Clutter also resulted in fewer eye fixations on critical information, justifying the concern about clutter in PFDs.

This work was funded, in part, by the Federal Aviation Administration
Supporting dynamic re-planning in multiple UAV control: a comparison of 3 levels of automation

Julie C. Prinet¹, Andrew Terhune¹ and Nadine B. Sarter¹

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI

Unmanned Aerial Vehicle (UAV) control currently requires multiple operators to supervise the mission of a single vehicle. The goal is to improve this ratio and have a single operator supervise up to 10 UAVs. Achieving this goal requires the introduction of automated systems that support multitasking and decision-making. However, there is uncertainty about the appropriate level of automation (LOA). The present study compared re-planning performance at three LOAs (manual, intermediate, full automation) of 30 participants who each supervised 9 UAVs. Full automation resulted in the best re-planning performance and matched intermediate automation in terms of target detection. The manual condition showed significantly poorer performance on these tasks, especially in high workload, but suffered the smallest loss of UAVs. Subjectively, most participants preferred intermediate automation, which they trusted more than full automation. The findings from this research help inform UAV system design and add to the knowledge base in human-automation collaboration.
Towards standardization of surgical procedures: human factors approach for identifying best techniques and surgical education

Denny Yu¹, Adam Frischknecht², Steven J. Kasten², Rebecca Minter², Pamela Andreatta³, Thomas J. Armstrong¹,

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
²Department of Surgery, University of Michigan, Ann Arbor, MI
³Department of Medical Education, University of Michigan, Ann Arbor, MI

Variations in technique commonly exist in surgical procedures and outcomes are known to vary between surgeons. The standardization of surgical procedures on techniques associated with good results can improve patient outcomes and systems outcomes. However, describing and quantifying the impact of technique on surgical outcomes remains difficult. The purpose of this work is to develop a methodology to reliably describe surgical procedures and surgeon technique. Hierarchical task analysis (HTA) was used to model variations in surgical techniques. Eight cases of the surgical procedure “microvascular anastomosis” were used to create a descriptive taxonomy and surgeon focus groups were conducted for taxonomy validation. The resulting taxonomy was applied to 73 anastomoses to identify differences between cases and surgeons. Results showed that a surgical procedure can be decomposed into a taxonomy of tasks, subtasks, and elements. The incorporation of work attributes to the HTA greatly reduced the size of the taxonomy and allowed for a rigorous techniques. Hypothesis testing found significant technique differences being performed between arteries and vein anastomosis. The application of the taxonomy showed that the proposed framework can be used to quantitatively test surgeon techniques. Although future work is needed to expand testing to other hypotheses and to associate technique variations with outcomes, the use of HTA and work attributes show promise in identifying variations for finding best practices in surgeon training, assessment, and education.

This work was funded, in part, by the Graduate Medical Education Innovations Program through the University of Michigan Health Systems, and by the National Science Foundation.
Defender-interdictor location models with uncertain futures
Kaiyue Zheng¹, Mark S. Daskin¹

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI

We model scenario-based two-stage ρ-robust defender-interdictor problems. The defender allocates resources to mitigate the interdictor's actions, while the interdictor wants to maximize damage while inflicting at least a minimal level of damage in each scenario. We present two models with different interdictor options. Algorithms and computational results are given.
Materials and Chemical Technology

Session Chair: Kenneth Cheng
Crystallization behavior and kinetics of electrodeposited amorphous Ni-P alloys

Peng-Wei Chu¹,², Chao-Sung Lin²

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
²Department of Materials Science and Engineering, National Taiwan University, Taipei, Taiwan

Amorphous alloys have unique microstructure and extraordinary properties, which give them great fundamental research value and wide application potentials. However, amorphous alloys are thermodynamically unstable and tend to crystallize under elevated temperature, limiting the application range of the material. Therefore, understanding the phase transformation process, mechanism and the resultant properties change is crucial for clarifying the utilizing limit of these amorphous alloys. Furthermore, by controlling the crystallization of amorphous alloys, new process of producing special nanostructure materials can be developed. In this research, the high temperature phase transformation process of electrodeposited amorphous Ni-25at%P alloy was investigated by thermal analysis and microstructure characterization techniques. The results show that the crystallization of electrodeposited amorphous Ni-P alloy is a two-step process. A metastable nickel-phosphorus intermetallic, NiₓPᵧ, crystallized at 250~300°C by ordered clusters and shearing deposition, followed by the direct phase transformation to thermodynamically stable Ni₃P after heating to 400~450°C. By Johnson-Mehl-Avrami crystallization kinetics analysis, the crystallization of the metastable Ni-P intermetallic has an activation energy of 230~250 kJ/mol with an Avrami exponent around 2~2.5. According to the crystallization analytical model, the crystallization process is a combination of mixed nucleation and 3D diffusion-controlled crystal growth. Last, based on the understanding of crystallization behavior and kinetics of amorphous Ni-P alloy, a nanocrystalline/amorphous composite structure alloy was fabricated by a controlled annealing process.

This work was funded by the National Science Council, Republic of China under Grant No. NSC 99-2815-C-002-094-E.
Atomic scale characterization of oxide/metal interface of zirconium alloys
Yan Dong\textsuperscript{1}, Arthur T. Motta\textsuperscript{2}, Emmanuelle A. Marquis\textsuperscript{1}

\textsuperscript{1}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Mechanical and Nuclear Engineering, the Pennsylvania State University, University Park, PA

Zirconium based alloys are widely used as cladding materials in nuclear power plants because of their low thermal neutron capture cross-section, adequate mechanical behavior and reasonable corrosion resistance. Yet, waterside corrosion remains a major concern and small differences in microstructure and alloying additions in the base metal result in significant differences in corrosion behavior. These differences need to be understood to ensure a better corrosion resistance and hence higher efficiency and longer fuel lifetime. In the present study, atom probe tomography (APT) and TEM are used to elucidate the factors controlling the oxidation behavior at interfaces and along grain boundaries in a series of Zr alloys. An oxide layer of ZrO\textsubscript{2} forms on oxidized pure zirconium, Zircaloy-4 and a Zr-Cr-Fe alloy. Intermediate layers are observed beneath the ZrO\textsubscript{2} layer with compositions corresponding to ZrO and Zr\textsubscript{2}O. All three materials show the similar sequence of phases, but the relative thickness intermediate layers and morphologies of interfaces vary significantly. Results also suggest the fine precipitation of Fe and Cr, segregation of Fe to linear features likely dislocations, and non-homogeneity in the distribution of Sn with segregation to the oxide interfaces and grain boundaries.

\textit{This work is funded, in part, by the Department of Energy, under the Nuclear Energy University Program.}
Effect of polymer architecture of the wetting properties of macromolecules
Bradley Frieberg\textsuperscript{1}, Emmanouil Glynos\textsuperscript{2}, Georgios Sakellariou\textsuperscript{4}, Peter F. Green\textsuperscript{1,2,3}

\textsuperscript{1}Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{4}Department of Chemistry, University of Athens, Panepistimiopolis, Zografou, Athens Greece

The wetting of a liquid, and its morphological features, on a surface are influenced by a combination of specific short-range molecular interactions, associated with the contact of the molecules with a substrate, and long-range algebraically decaying intermolecular forces acting over longer length-scales of many nanometers. As an example, polystyrene films of thicknesses on the order of nanometers supported by oxidized substrates, may become unstable (or metastable) breaking-up forming two collections of droplets: macroscopic droplets, characterized by macroscopic contact angles, surrounded by considerably smaller droplets of nano-scale dimensions. We show that star-shaped PS molecules exhibit notably different wetting properties than their linear analogs of the same chemical structure. Depending on the functionality (number of arms) and degree of polymerization of the star-shaped molecules, their equilibrium contact angles and line tensions of macroscopic droplets are approximately 1 and 2 orders of magnitude smaller than linear polymers, respectively. Unlike linear macromolecules, the macroscopic droplets of star-shaped polymers of sufficiently high functionality reside on a layer of molecules adsorbed on the substrate. Notably, the adsorbed layers formed by these branched polymers exhibit surprising structural stability, which increases with increasing functionality of the stars. The structure of the films is reconciled in terms of an effective interface potential that characterizes the role of the intermolecular forces, which is explained in terms of entropic effects associated with the “packing” of macromolecules at interfaces. These findings have implications for applications that include surface modification, patterning and adhesion.

\textit{This work was funded, in part, by the National Science Foundation (NSF), Division of Material Research.}
Microporous coordination polymers: a new class of adsorbents for energy-efficient air dehumidification

Ping Guo\textsuperscript{1}, Dhanadeep Dutta\textsuperscript{2}, David W. Gidley\textsuperscript{2}, Adam J. Matzger\textsuperscript{3}

\textsuperscript{1}Department of Chemistry, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Physics, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Department of Chemistry and Macromolecular Science and Engineering, Ann Arbor, MI

Removal of water from air and other gases is commonly accomplished by passing the gases through desiccant beds. However, conventional sorbents such as alumina have some drawbacks including low water capacities and a large energy input for regeneration. Microporous coordination polymers (MCPs) offer the potential for significantly higher uptake and regeneration at relatively low temperatures. One of the critical challenges for the industrial application of MCPs as desiccants is their water stability and regenerability over multiple hydration and regeneration cycles. Moisture can cause irreversible structural collapse of MCPs, resulting in decreased surface areas and sorption capacities. The high potential capacity for water in MCPs underscores the importance of understanding the interactions between water and MCPs. Here we discuss the moisture-induced degradation mechanism of MCPs using PXRD analysis, gas adsorption measurements and positronium annihilation lifetime spectroscopy techniques. Our work provides insight into the modulation of surface areas, structures and chemical functionalities of MCPs tailored for water adsorption under industrially relevant conditions.

\textit{This work was funded, in part, by [National Science Foundation].}
Shear transformation zones in an Al-based metallic glass probed by anelastic relaxation experiments

Jong Doo Ju¹, Dongchan Jang², Amadi Nwankpa³ and Michael Atzmon¹,⁴

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
²Department of Materials Science and Engineering, California Institute of Technology, Pasadena, CA
³Computer Aided Engineering Network, University of Michigan, Ann Arbor, MI
⁴Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

We have characterized shear transformation zone (STZ) properties using anelastic relaxation experiments with an Al-based metallic glass. In order to cover a wide range of time constants, a combination of cantilever bending and bend-stress relaxation experiments were employed to measure anelastic strain as a function of time, with the latter spanning over 7 orders of magnitude (from a second to 1 year.) Direct spectrum analysis, which were tested extensively to rule out artifacts, yielded relaxation-time spectra. Surprisingly for amorphous materials, the spectra exhibit distinct peaks. Analysis using a linear solid model and activated-state rate theory revealed that the peaks correspond to a quantized hierarchy of STZs with increments of a single atomic volume, ranging from 14 to 21 atoms. In addition to the quantized nature of the STZs, the volume fraction occupied by potential STZs was obtained. It is as high as 25 % (with multiple counting of overlapping potential STZs.) The anelastic relaxation measurements have been repeated for an annealed metallic glass to examine the effects of structural relaxation on STZ properties as well. The experimental results suggested that the size of STZs and their quantized properties remained the same. The volume fraction of potential STZs, however, decreased substantially by annealing, which is in good accord with previous experimental observations. The annihilation of potential STZs retards anelastic flow in a metallic glass, and the implications for the understanding of mechanical/structural relaxation will be presented.

This work was funded by US National Science Foundation (NSF), Grant No.DMR-0605911.
Time resolved SAXS measurements of UV–induced restructuring during gelation of nanoparticle dispersions

K. Anne Juggernauth\textsuperscript{1,2}, Soenke Seifert\textsuperscript{3} and Brian J. Love\textsuperscript{1,2,4}

\textsuperscript{1}Macromolecular Science & Engineering Research Center, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{3}X-Ray Sciences Division, Argonne National Labs, Argonne IL
\textsuperscript{2}Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

Responsive systems exhibiting a phase change have become the subject of increasing amounts of research in the recent years. These range from shape memory alloys to stimuli – responsive polymers and composites. The current work focuses on a nanoparticle dispersion containing colloidal Laponite nanoparticle, a triblock copolymer (Pluronic F127) and a photo acid generator (PAG) which exhibits a liquid to gel transition upon UV illumination. We have probed the liquid to gel transition kinetics using \textit{in-situ} photorheology; however, the structural changes that occur are not well understood. Here, we use simultaneous \textit{in-situ} UV – SAXS as a method of tracking structural changes induced by UV exposure at room temperature. Our data shows that this system exhibits a peak in the structure factor of the system which can be correlated to the inter – particle spacing within the probed volume. The changes in this peak position and shape over time are directly related to the physical structure within the sample and the time scale taken for the system to undergo reach a stable state. The structural evolution at the nanoscale is directly related to the bulk liquid to gel phase transition.

\textit{Use of the Advanced Photon Source was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.}
Hygro-responsive membranes for effective oil-water separation

Gibum Kwon\textsuperscript{1}, Arun K. Kota\textsuperscript{1}*, Wonjae Choi\textsuperscript{2}, Joseph M. Mabry\textsuperscript{3}, and Anish Tuteja\textsuperscript{1,4}

\textsuperscript{1}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Mechanical Engineering, University of Texas-Dallas, Richardson, TX
\textsuperscript{3}Space and Missile Propulsion Division, Air Force Research Laboratory, Edwards Air Force Base, CA
\textsuperscript{4}Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI

There is a critical need for new energy-efficient solutions to separate oil-water mixtures, especially those stabilized by surfactants. Traditional membrane-based separation technologies are energy-intensive and further limited, either by fouling or the inability of a single membrane to separate all types of oil-water mixtures. The ideal membrane for solely gravity-driven separation of oil-water mixtures is expected to be both hydrophilic and oleophobic, in air and under water. Here we report novel membranes with hygro-responsive surfaces, which are both superhydrophilic and superoleophobic, in air and under water. Our membranes can separate, for the first time, a range of different oil–water mixtures in a \textit{single unit operation}, with more than 99.9% separation efficiency, by using the difference in capillary forces acting on the individual phases. Our separation methodology is \textit{solely gravity driven} and consequently is expected to be highly energy efficient. We demonstrate the separation of several liters of oil–water mixtures using a scaled-up apparatus. We also demonstrate continuous separation of oil–water emulsions for over 100 hours without a decrease in flux. We anticipate that our separation methodology will have numerous applications, including the clean-up of oil spills, wastewater treatment, fuel purification and the separation of commercially relevant emulsions.

\textit{This work was funded by the Air Force Office of Scientific Research under grants FA9550-10-1-0523 and LRIR-92PLOCOR.}
Efficiency enhancement of thin upgraded metallurgical-grade Si solar cells on flexible substrates

Jae Young Kwon\textsuperscript{1}, Duck Hyun Lee\textsuperscript{2}, Michelle Chitamber\textsuperscript{2}, Stephan Maldonado\textsuperscript{2}, Anish Tuteja\textsuperscript{1}, Akram Boukai\textsuperscript{1}.

\textsuperscript{1}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Chemistry, University of Michigan, Ann Arbor, MI

The solar cell market has experienced tremendous growth in past several years, and silicon accounts for more than \textasciitilde90\% of the market due to advantages of earth abundance, good reliability, performance and a wealth of silicon materials processing knowledge. However, the high cost (\textasciitilde$1/W) of solar-grade Si solar cells has hindered their immediate adoption in the commercial market. Other research avenues, such as the use of upgraded metallurgical-grade Si, amorphous-silicon (a-Si) and silicon microwires, have recently been explored for their potential in lowering fabrication costs. Here, we present a thin film (<20\textmu m) solar cell based on upgraded metallurgical-grade polycrystalline Si that utilizes localized surface Plasmon enhancement and achieves an efficiency of >8\%. This efficiency rivals that of single junction a-Si without any degradation in performance over time as observed in a-Si. In addition, the solar cells are flexible and semitransparent so as to reduce balance of systems costs and open new applications for conformable solar cell arrays on a variety of surfaces. Detailed evaluations of the optical and electrical properties of these thin film upgraded metallurgical-grade silicon solar cells indicate that additional improvements in efficiency are possible.

This work was funded, in part, by National Science Foundation (grant CBET-1066447) and Air Force Office of Scientific Research (grant FA9550-11-1-0017).
In situ rheology of *Staphylococcus epidermidis* bacterial biofilms
Leonid Pavlovsky¹, John G. Younger², Michael J. Solomon¹

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
²Department of Emergency Medicine, University of Michigan, Ann Arbor, MI

We developed a method to grow *Staphylococcus epidermidis* bacterial biofilms and characterize their rheological properties *in situ* in a continuously-fed bioreactor incorporated into a parallel plate rheometer. The temperature and shear rates of growth modeled bloodstream conditions, a common site of *S. epidermidis* infection. We measured the linear elastic (G’) and viscous moduli (G”) of the material using small-amplitude oscillatory rheology and the yield stress using non-linear creep rheology. We found that the elastic and viscous moduli of the *S. epidermidis* biofilm were 11±3 Pa and 1.9±0.5 Pa at a frequency of 1 Hz and that the yield stress was approximately 20 Pa. We modeled the linear creep response of the biofilm using a Jeffreys model and found that *S. epidermidis* has a characteristic relaxation time of approximately 750 seconds and a linear creep viscosity of 3000 Pa·s. The effects on the linear viscoelastic moduli of environmental stressors, such as NaCl concentration and temperature, were also studied. We found a non-monotonic relationship between moduli and NaCl concentrations, with the stiffest material properties found at human physiological concentrations (135 mM). Temperature dependent rheology showed hysteresis in the moduli when heated and cooled between 5°C and 60°C. Through these experiments, we demonstrated that biofilms are rheologically complex materials that can be characterized by a combination of low modulus (~10 Pa), long relaxation time (~10³ seconds), and finite yield stress (20 Pa). We conclude that biofilms should be viewed as soft viscoelastic solids whose properties are determined in part by local environmental conditions.

This work was funded, in part, by the NSF CDI Program and the NIGMS.
Enhancement of thermopower and mobility in bulk p-type nanostructured Ti$_{0.5}$Hf$_{0.5}$Co$_{1+x}$Sb$_{0.9}$Sn$_{0.1}$ half-Heusler composites

Pranati Sahoo$^{1,2}$, Julien P. A. Makongo$^1$, Nathan Takas$^1$, Sung Joo Kim$^1$, Xiaoyuan Zhou$^2$, Xiaoqing Pan$^2$, Ctirad Uher$^3$, Pierre F. P. Poudeu$^{1,2}$

$^1$Laboratory for Emerging Energy and Electronic Materials, Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
$^2$Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
$^3$Department of Physics, University of Michigan, Ann Arbor, MI

Designing thermoelectric materials with large figure of merit (ZT) has proven extremely difficult over the past six decades, despite breakthroughs concerning lattice thermal conductivity reduction using nanostructuring or enhancements in the Seebeck coefficient through distortion of electronic density of states, because of the interdependence between electronic (thermopower, electrical conductivity) and thermal transport properties. In this work, we show that these materials transport parameters can be decoupled and enhanced simultaneously using sub-ten nanometer scale inclusions coherently embedded in the semiconducting matrix. We focus our study on the effect of the volume fraction of full-Heusler (FH) nanoinclusions on electronic and thermal transports in a bulk half-Heusler (HH) matrix with composition Ti$_{0.5}$Hf$_{0.5}$Co$_{1+x}$Sb$_{0.9}$Sn$_{0.1}$. The HH(1-x)/FH(x) nanocomposites, with general formula Ti$_{0.5}$Hf$_{0.5}$Co$_{1+x}$Sb$_{0.9}$Sn$_{0.1}$, were synthesized by solid state combination of the elements (with small excess “x” of elemental Co) at 950 °C. The resulting products consist of polycrystalline fine powders with HH structure. Transmission electron microscopy studies revealed that individual grains of the as-synthesized product contain nanocrystals with FH structure that are coherently embedded inside the HH matrix. The population density and mole fraction of the FH phase within the composites is controlled by the excess “x” of elemental Co used in the starting mixture. All the samples showed p-type semi-conducting behavior.Regardless of the temperature, the thermopower gradually increases with increasing mole fraction of FH inclusion (from 100 µV/K for x = 0 to 240 µV/K for x = 0.05 at 300K), reaches a maximum for x = 0.05 and gradually decrease with further increase in FH concentration. The effect of nanostructuring on the thermoelectric performance of Ti$_{0.5}$Hf$_{0.5}$Co$_{1+x}$Sb$_{0.9}$Sn$_{0.1}$ composites will be discussed using electron microscopy, electronic charge transport and thermal conductivity data.
This work is supported by the start-up fund from the College of Engineering, University of Michigan. The TEM work was performed using a JEOL 2010F TEM purchased with NSF award # DMR-0723032 and # DMR-0315633 in the Electron Microbeam Analysis Laboratory (EMAL) at the Univ. of Michigan.
A probabilistic crystal plasticity model for modeling grain shape effects based on slip geometry

Shang Sun\textsuperscript{1}, Veera Sundararaghavan\textsuperscript{2}.

\textsuperscript{1}Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Although polycrystal plasticity theories and finite element methods for analyzing microstructures are fairly well developed, finite element simulations are computationally prohibitive, especially in the context of enabling multiscale process modeling and product design. A new statistical theory is introduced that takes into account the coupling between grain size, shape and crystallographic texture during deformation of polycrystalline microstructures. A “grain size orientation distribution function” (GSODF) is used to encode the probability density of finding a grain size $D$ along a direction (given by unit vector $n$) in grains with orientation $g$. The GSODF is sampled from the input microstructure and is represented in a finite element mesh. During elastoplastic deformation, the evolution of grain size $D$ (in direction $h$) and the orientation $g$ is tracked by directly updating the GSODF probabilities using a Lagrangian probability update scheme. The effect of grain shape (e.g. in high aspect ratio grains) is modeled by including the apparent grain size as seen by various different active slip systems in the grain within the constitutive law for the slip system resistance. The prediction of texture and strains achieved by the statistical approach is compared to Taylor aggregate and finite element deformation analysis of a planar polycrystalline microstructure. The role of grain shape and size in determining plastic response is investigated and a new adaptive GSODF model for modeling microstructures with multimodal grain shapes is proposed.

\textit{This work was funded by [Office of Naval Research (ONR) grant N00014-12-1-0013 and National Science Foundation CAREER award (CMMI-0954390)].}
Characterization of PEO-PPO-PEO amphiphilic triblock copolymers using differential scanning calorimetry (DSC)

Andre L. Thompson¹, Brian J. Love²

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

I am characterizing structural changes that arise in the polyethylene oxide-polypropylene oxide-polyethylene oxide (PEO-PPO-PEO) amphiphilic triblock copolymers (commercially known as Pluronics) as a function of temperature through Differential Scanning Calorimetry (DSC). Pluronic® P-105 (BASF Corp) (Mw = 6.5Kg/mol) has been evaluated most extensively. I am also measuring how adding small amounts of Methyl Paraben (MP) perturb the structure and the driving force for micelle formation in aqueous PEO-PPO-PEO solutions with different block lengths. Micelle formation is an aggregate of surfactant molecules dispersed in solution. Hydrophilic heads interact with surrounding aqueous solvent while hydrophobic tails form the micelle center. This new evolving structure can be resolved by Differential Scanning Calorimetry (DSC). DSC is a thermo analytical technique where the difference in the amount of heat required to increase the temperature of a sample and a reference is tracked with temperature. Methyl Paraben is commonly used as preservatives by the cosmetic and pharmaceutical industries. It is found in fruits where it acts as an antimicrobial agent and kills or inhibits the growth of microorganisms. Future experiments will focus on resolving the driving force for micelle formation in the presence of drug mimics. We are ultimately trying to resolve how drugs incorporated into dispersion-based drug delivery vehicles affects their solidification characteristics when heated to body temperature.

This work was funded, in part, by Rackham Graduate School Summer Institute.
Shape dependence of oxygen reduction activity on Ag nanoparticles
Timothy Van Cleve\textsuperscript{1} and Suljo Linic\textsuperscript{1}

\textsuperscript{1}Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

To mitigate negative economic and environmental consequences arising from our dependence on petroleum, there is a definite need to develop alternative energy systems such as low temperature fuel cells. Low temperature fuel cells generate electrical energy and water by reacting hydrogen and oxygen gases. It has been well established that the majority of the energy losses originates from the oxygen reduction reaction at the cathode. Currently, fuel cells are limited by large kinetic overpotential, limited stability, and high material cost of platinum electrodes. With recent advances in anion exchange membranes, cheaper materials have become available as potential cathodes in low temperature alkaline fuel cells. In particular, we are investigating Ag nanoparticles as alternative electrocatalysts for oxygen reduction. Different particle geometries have different distributions of surface facets, which have distinct chemical and catalytic properties. Specifically, we are interested in examining differences in activity between nanoparticles terminated with primarily 100 and 111 facets. In this work, silver nanoparticles of several geometries are synthesized using several colloidal routes prior to being deposited onto a Vulcan XC72R support. Kinetic current and electrochemical surface area measurements are obtained using linear sweep and cyclic voltammetry with a rotating disc electrode in a three electrode electrochemical cell. Silver nanospheres are shown to have slightly higher mass and specific kinetic currents compared to nanocubes. Our results are consistent with previous work on silver single crystal electrodes.

\textit{This work was funded, in part, by the Department of Energy.}
Local dynamics of chains confined to organized micellar structures
Hengxi Yang\textsuperscript{1}, X. Chelsea Chen\textsuperscript{2}, Junnan Zhao\textsuperscript{3}, and Peter F. Green\textsuperscript{2,3}.

\textsuperscript{1}Department of Physics, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

We examined the formation, spatial organization and local dynamics of micelles of 20wt\% polystyrene-\textit{b}-polyisoprene (PS-\textit{b}-PI) in PS host. The copolymer chains form micelles in thin films, with the PI-block forming the micelle cores and the PS-block forming the corona. The diameter of the cores increases with increasing PS host length, saturating at large value; meanwhile the number density of micelles in the film decreases. The micellar structures are also thickness dependent: The ones in 110 nm films are spherical, while cylindrical ones appear with increasing number of copolymer chains (in thicker films). For systems in which the PS host chains penetrate into the micelle corona, the aspect ratio of cylindrical micelles increases as the film thickness increases. However, if the PS host chains do not penetrate into the corona, the copolymer chains form a micron-size “onion-like” structure in microns-thick films and bulk samples. Given that the glass transition temperature ($T_g$) of PI is $>100$ K lower than that of PS, at room temperature the PI-block is essentially anchored and confined between the rigid PS walls. Broadband dielectric spectroscopy measurements showed that the dynamics of PI in micelles are much faster (with $T_g$ over 15 K lower) than those in gyroid structure (for pure PS-\textit{b}-PI), while the dynamics of PI in “onion-like” structure lie between the two. The dramatic increase in dynamics from gyroid to micellar structure is owing to the confinement geometry, e.g. interfacial curvature, rather than the dimension of the confinement; this has rarely been observed in the literature.

This work is funded by the National Science Foundation.
Hierarchical Polymer Nanocomposites with Novel Properties

Jian Zhu, Christine A. Andres, Huanan Zhang, Bongsup Shim, Ming Yang and Nicholas A. Kotov

Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

Advanced technologies especially in electronics and energy fields require advanced material platforms with simultaneous optimization of several material properties at once. Fabrication of a nanocomposite with the hierarchical structure similar to materials in nature can be a universal methodology to address this issue. Here I will discuss my work to fabricate those types of composites by three methods: layer-by-layer (LBL) assembly, vacuum assisted flocculation (VAF), and template infiltration (TI), which are showcased for fabrication of novel nanocomposites for carbon nanotube (CNT), graphene, and aramid nanofibers. Those nanocomposites can have unique mechanical, electrical and thermal properties. For example, CNT, graphene and aramid fiber composites by LBL assembly, VAF or TI can give rise to a highly desirable balance of strength and toughness. The intricacy of LBL assembly is demonstrated to control the band gap of CNT thus giving the CNT coating a combination of high conductivity, transparency as well as robustness. In addition, the hierarchical assemblies of graphene oxide have a distinctive negative thermal expansion property, which can also be tuned by including polymers between the layers. What is more, this methodology can be further used to fabricate nanocomposite microfibers with strength and toughness catching up with the silk.
Micro-
Electromechanical
Systems

Session Chair: I-Ning Hu
GaN-based micro-mechanical resonators for timing applications
Azadeh Ansari\textsuperscript{1}, Mina Rais-Zadeh\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Extensive research has been recently conducted on optoelectronic (detectors, blue LEDs) and electronic (high power, high temperature, high frequency) properties of gallium nitride (GaN)-based materials. Being a wide band-gap semiconductor (3.4 eV), GaN exhibits high saturation velocity, high breakdown electron field, and high sheet carrier density, rendering its chemical and mechanical stability even at elevated temperatures. Furthermore, GaN-based materials exhibit excellent mechanical and piezoelectric properties, which make them perfect candidates for micro-electromechanical systems (MEMS) applications (e.g. resonators, strain detectors, chemical detectors, and etc.). Intimate integration of GaN MEMs resonators and GaN electronics opens up wide area of applications to build up monolithic all-GaN systems, able to operate at higher temperatures and harsh environments where Si technology falls short. Very high Quality factors ($Q$) resonators with high power handling capability and record $freq \times Q$ values have been reported for bulk-mode GaN-only and GaN-on-Si resonators. Integration of High $Q$ resonators with AlGaN/GaN High Electron Mobility Transistors (HEMTs) is a starting point to build a monolithically-integrated oscillator based on GaN HEMT and MEMS resonator. These frequency references can replace the traditionally-used quartz crystal oscillator or even CMOS-integrated AlN piezoelectric MEMS oscillators, since GaN offers superior material properties compared to Si.
A scalable, modular, multi-stage, peristaltic, electrostatic gas micro-pump
Ali Besharatian\(^1\), Karthik Kumar\(^2\), Rebecca L. Peterson\(^1\), Luis P. Bernal\(^2\), Khalil Najafi\(^1\)

\(^1\)Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\(^2\)Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Gas micropumps are needed in many emerging applications, including gas chromatography, resonant/IR sensors, atomic clocks, and mass spectrometers. High pressure and flow are important requirements, which in turn require large-stroke and/or high-frequency actuators with low power consumption and small size. Previous gas micropumps exhibit limited capabilities due to use of bulky actuators, often were slow or power/size inefficient, and lacked scaling/integration capabilities. Our group introduced the first electrostatic peristaltic gas micropump, which utilized fluidic resonance and a multi-stage configuration to achieve the highest recorded flow and pressure in a low-power and small-volume system. However, it had inherent limitations in scalability, sealing and yield due to challenging alignment and bonding. This project seeks to develop a MEMS pump that can be used as the roughing pump in a three-part micro-scale vacuum system. The new pump utilizes the same operating principle as previously reported, but with major modifications in device architecture, totally new fabrication technology and modular assembly/packaging. The modular fabrication technology has a final process yield of 90% with a high throughput and high control over critical design parameters (<5% error). Moreover, the device total size is 60% smaller than the old design, due to the use of a novel honeycomb planar architecture. Under preliminary testing, the microfabricated 24-stage pump successfully produced a flow rate of 0.36sccm and a pressure accumulation of ~500Pa at 22kHz.

This work is supported by the DARPA-CVMP program under grant #W31P4Q-09-1-0011. Portions of this work were performed in the University of Michigan’s Lurie Nanofabrication Facility (LNF).
Packaging of silica for timing & inertial measurement

Zongliang Cao\textsuperscript{1}, Jialiang Yan\textsuperscript{1}, Yi Yuan, Jae Yoong Cho\textsuperscript{1}, Guohong He\textsuperscript{1}, Rebecca L. Peterson\textsuperscript{1}, and Khalil Najafi\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Timing and inertial measurement units (TIMU) consist of a package of accelerometers and gyroscopes along with a clock. They are widely used for navigational guidance in avionics as well as ships. MEMS inertial measurement units have to-date been built as discrete components integrated at the system level. Challenges in wafer-level integration include the large size of individual devices, coupling between devices, conflicting process and package requirements for different devices, as well as concerns over impact on device performance. In this project, we build an extremely compact, integrated TIMU using a multi-layer stack of fused silica containing both the devices and packaging. By vertically stacking multiple thin device layers, we greatly reduce the volume of our device to less than 1/20\textsuperscript{th} of a penny. Fused silica was chosen due to its excellent physical properties. It has a low coefficient of thermal expansion, good thermal and electrical resistance, and the potential for higher Q devices than silicon. Key technologies developed include a high aspect ratio etching of fused silica and vertical vias through silica. Work is ongoing on multi-layer vacuum packaging and process integration.

\textit{This work is supported by DARPA TIMU award \#N66001-11-C-4170. Portions of this work were performed in the University of Michigan’s Lurie Nanofabrication Facility.}
High performance rate-integrating gyros
Jae Yoong Cho¹, Jialiang Yan¹, Becky Peterson¹, Khalih Najafi¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

In this project we are developing new designs and fabrication processes for high-performance MEMS rate-integrating gyroscopes (RIG). The key advantages of the micro-RIG include direct angular readout, large full-scale range (> 100 °/s), and large bandwidth (> 100 Hz). We have developed a novel Si RIG and are developing next-generation RIG using high-Q materials. The single-crystal Si Cylindrical Rate-Integrating Gyroscope (CING) is made of (111) Si using the Si-On-Glass (SOG) process. The key advantages of the CING include a fully axisymmetric resonator, self-alignment of the resonator to the anchor and electrodes, and a large parasitic-to-wineglass mode frequency ratio of greater than 1.7. The geometry minimizes the stiffness and damping anisotropy, which leads to reduced bias drift; the large frequency ratio leads to lower vibration and shock sensitivity. Two versions of the CING operate at 18 kHz and 3 kHz. The 3-kHz CING measures an outer radius of 6 mm, an inner radius of 1.5 mm, and a height of 320 µm. The gyro has a Q of ~100,000 at < 5 mTorr, an original frequency mismatch, Δf, of 7 Hz, and a damping mismatch, Δ1/τ, where τ = 2Q/ω, of 10 mHz. Using digital interface circuitry under precise mode matching (Δf < 20 mHz), the CING measures an angle random walk of 2.6 °/√Hr and a bias stability of 203 °/Hr in rate-sensing mode. In rate-integrating mode, the CING measures a constant angular gain (Ag~0.01) over mode mismatch of 20~80 mHz for several days without accurate temperature control.

This work was funded, in part, by [DARPA HERMIT award #W31P4Q-04-1-R001 and DARPA MRIG award #W31P4Q-11-1-0002]. Portions of this work were performed in the University of Michigan’s Lurie Nanofabrication Facility.
A vibration harvesting system for bridge health monitoring applications
James McCullagh\textsuperscript{1}, Rebecca L. Peterson\textsuperscript{1}, and Khalil Najafi\textsuperscript{1}

\textsuperscript{1}Department of Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI

Energy can be scavenged from vibrations in the surrounding environment. One possible application is to harvest vibrations from a bridge to power bridge health monitoring sensors. Sensing a bridge's structural integrity at hard to reach positions will be made easier if energy can be harvested to power distributed wireless sensor nodes, eliminating the need for expensive and inconvenient wired power or battery replacement. This abstract presents a system comprising of electronics and an electromagnetic energy harvester used for scavenging the low-frequency, low amplitude, and non-periodic vibrations present on bridges. The energy harvester in this system is the Parametric Frequency Increased Generator (PFIG). The PFIG, designed at Michigan, uses a non-resonant architecture that up-converts the low frequency bridge vibrations found on bridges to higher frequencies. A new design for electronics uses the PFIG's two outputs which are fed into two transformers. The transformer outputs are fed into two cascaded three-stage Cockcroft multipliers used to rectify and boost the harvester outputs and build charge on a storage capacitor. Both short-term and long-term test were completed on the New Carquinez bridge in CA. Best results showed that an average of over 5\(\mu\)W was harvested over a period of 120 seconds by the PFIG. The electronics could regularly charge a 10\(\mu\)F storage capacitor to between 1V and 2V. Long term tests have shown that the PFIG has remained operational for 4 months demonstrating this design's long term robustness. Hardware evaluation is in progress on an IC designed to improve recovered power from the PFIG.

\textit{This work was funded, in part, by National Institute of Standards and Technology (NIST) Technology Innovation Program (TIP) under Cooperative Agreement Number 70NANB9H9008}
Surface micro-machined piezoelectrically transduced fused silica resonators
Adam Peczalski\textsuperscript{1}, Zhengzheng Wu\textsuperscript{1}, Vikram Thakar\textsuperscript{1}, Zongliang Cao\textsuperscript{1}, Yi Yuan\textsuperscript{1}, Guohong He\textsuperscript{1}, Rebecca L. Peterson\textsuperscript{1}, Khalil Najafi\textsuperscript{1}, and Mina Rais-Zadeh\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

This paper reports a fused silica based surface micro-machined piezoelectric MEMS resonator for use in timing devices. Microelectro-mechanical system (MEMS) resonators have been developed as a replacement to quartz based crystal resonators for use in various timing applications. MEMS resonators show a smaller form factor and lower power consumption as compared to quartz-based resonators, and therefore are an attractive alternative for use in modern compact devices. Fused silica was chosen for the substrate material due to its excellent thermal properties. Fused silica has very high thermal isolation, greatly reducing losses from thermoelastic damping (TED). This gives a distinct advantage over silicon devices, especially at lower frequencies. For this work, piezoelectric actuation was chosen over electrostatic actuation to remove dependence on actuation gaps and increase fabrication tolerances. A piezoelectrically transduced I-shaped bulk acoustic resonator (IBAR) device is demonstrated in both the length-extensional and flexural modes. The IBAR devices show center frequencies of up to 3MHz with quality factors of $\sim 16,000$. To the best of the author’s knowledge, this is the first time that fused silica surface micro-machined MEMS devices have been demonstrated.

*This work was funded in part by DARPA under the Timing and Inertial Measurement Unit (TIMU) program.*
Characterization of GeTe for RF switching applications
Yonghyun Shim¹, Gwendolyn Humme¹, and Mina Rais-Zadeh¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109

Phase change materials are charcogenide compounds that can switch between crystalline and amorphous states by applying specific heating conditions for each transition. Because of sufficient life cycle, fast switching speed, and high density integration with CMOS technologies, these materials are currently utilized for non-volatile memory applications. Within diverse stoichiometric compositions of GeSbTe, Ge₅₀Te₅₀ was selected, due to a low crystalline resistance and a high ON/OFF resistance ratio. RF switches were fabricated using Ge₅₀Te₅₀ vias with silicon dioxide and gold electrodes in the stack. The crystalline resistance of around 1 Ω is achieved by applying a 1V pulse with a pulse width of 200 μs and a rise and fall time of 200 μs. The measured resistance in the amorphous state is more than 100 kΩ. The pulse width for amorphization is 2 μs with a rise and fall time of 5 ns and amplitude of 2.5-3.5 V. The ON/OFF resistance ratio is above 10⁵, which is close to the bulk material property of 10⁶. Although further investigation is necessary for more reliable phase change and lower crystalline resistance, Ge₅₀Te₅₀, is a promising material for RF reconfigurable system, especially for tunable passive components such as capacitors, inductors, matching networks, phase shifters, and filters.
Temperature compensation of piezoelectrically actuated flexural mode resonators

Vikram Thakar\textsuperscript{1}, Zhengzheng Wu\textsuperscript{2}, Adam Peczalski\textsuperscript{2} and Mina Rais-Zadeh\textsuperscript{2}

\textsuperscript{1}Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Micromechanical resonators are ubiquitous in timing references due to their high quality factors but suffer from a relatively large temperature sensitivity. Passive compensation via the deposition of a compensating material is a commonly implemented strategy to mitigate this problem. In this work we explore the spatial dependence of passive temperature compensation using a piezoelectrically actuated flexural resonator as the platform. Using finite element results we show that the passive compensation of micromechanical resonators can be optimized by placing compensating material in areas of high strain energy density. The implementation is straightforward with the use of trenches refilled with the compensating material. We demonstrate piezoelectric transduction of in-plane flexural-mode silicon resonators with a center frequency in the range of 1.3 – 1.6 MHz and use them for the experimental investigation of the proposed passive temperature compensation strategy. A fabrication technique utilizing oxide-refilled trenches is implemented to achieve efficient temperature compensation for such resonators while maintaining compatibility with wet release processes. As proof of concept, a high-Q (> 19,000) resonator having a low TCF of $< 2 \text{ ppm/°C}$ and a turnover temperature of around 90 °C, ideally suited for use in an ovenized platform is demonstrated. This technique will allow the rapid development of novel resonators with optimal temperature characteristics for use in oscillators and timing references.

\textit{This work was supported by DARPA under the Timing and Inertial Measurement Unit (TIMU) program.}
Switchable wide tuning range bandstop filters for frequency-agile radios
Zhengzheng Wu¹, Yonghyun Shim¹, and Mina Rais-Zadeh¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Tunable filters play an important role in frequency-agile RF front-ends for reconfigurable or software-defined radios. With preselect RF filters used, the receiver is protected from gain desensitization in the presence of strong out-of-band interferers, and the receiver linearity requirement is significantly relaxed. Tunable bandstop filters provide a high level of rejection and very low passband insertion loss that minimize the degradation of receiver noise figure in the presence of interferences, showing potential to replace more complicated and higher loss switched filter banks used in reconfigurable RF front-ends. Bandstop filters also find applications in improving Tx/Rx isolation and reducing transmitter spurious emission. This paper reports on the implementation of tunable bandstop filters that achieve octave (>200%) tuning range. Both high rejection level (> 30dB) and low passband loss (< 1dB) are achieved, showing significant improvement over other reported miniaturized tunable bandstop filters. Also, for the first time, both continuous frequency tuning and switch on-off capabilities are realized for bandstop filters through co-design of RF MEMS tunable capacitors and ohmic switches. The filters are realized using an integrated passive device (IPD) technology on a silicon substrate. In the IPD process, high-Q inductors, RF MEMS tunable capacitors and ohmic switches are simultaneously fabricated, providing a highly integrated solution. The tunable filters reported in this work prove to be the most compact size filters reported in the low SHF range.

This work was funded by National Science Foundation.
High-frequency large-deflection electrostatic diaphragm actuators with maximized volume displacement

Seow Yuen Yee¹, Rebecca L. Peterson¹, Luis P. Bernal² and Khalil Najafi¹.

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
²Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Many MEMS applications such as micro propulsion, micro gas pumping, microchip cooling and micro speaker require high-deflection (>5µm) and high-frequency (>50kHz) actuators which displace a large air volume. Highly-stressed thin diaphragms (~74MPa) with a large gap (>8µm) between the diaphragm and perforated electrode are fabricated. We use a simple 3-mask process that eliminates challenging manufacturing steps such as wafer to wafer bonding to improve process yield and throughput. The fabrication process also allow easy manipulation of the size and shape of the electrode: for example, filleted electrodes can be made by shaping the sacrificial photoresist layer through a reflow process. The filleted electrode devices have near 100% volume displacement under pull-in. The reliability of the filleted electrode diaphragms has been investigated through several long-term tests with different degrees of mechanical and electrical stress. To mimic a worst-case scenario with severe charging effects, the diaphragm is collapsed and held to the bottom electrode with a 50% duty cycle pulse wave. Stiction is observed after almost 1 hour of continuous actuation. In contrast, when using a 20% duty cycle pulse wave to minimize the time the diaphragm is in contact with the electrode, the actuators worked continuously for more than 43 days with no stiction or diaphragm breakage observed. Ongoing efforts include the assembly and further optimization of the cavities with actuators to generate high speed air jets.

This work was funded by DARPA-CSVMP grant #W31P4Q-09-1-0011. Portions of this work were performed in the University of Michigan's Lurie Nanofabrication Facility.
Microfluidics

Session Chair: Yu-Chih Chen
Integrated microfluidic chip for efficient Isolation and functional immunophenotyping of subpopulations of immune cells

Weiqiang Chen¹, Nien-Tsu Huang¹, Boram Oh¹, Timothy T. Cornell², Thomas P. Shanley², Katsuo Kurabayashi¹, and Jianping Fu¹,³.

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
²Department of Pediatrics and Communicable Diseases, University of Michigan, Ann Arbor, MI
³Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

Sepsis is a serious clinical condition that represents a patient's immune response to a severe infection and has a very high mortality rate. The immune response in septic patients is dynamic and patient-specific, and such complex heterogeneity in septic patients' immune response has made efficient therapies for sepsis very challenging. As such, there is an urgent need for new immunomonitoring technologies that can perform rapid and accurate cellular functional assays on patient immune cells in order to define and characterize the “immunophenotype” of septic patients. Here, we developed an integrated microfluidics-based immunomonitoring technology platform that can perform efficient isolation and rapid, accurate, and sensitive cellular functional assays on subpopulations of immune cells from septic patient blood. We utilized our newly developed poly-dimethylsiloxane (PDMS) surface micromachining technique to fabricate a two-layer PDMS microfluidic chip, with the top microfluidic chamber and microfiltration membrane designed for immune cell isolation and culture and the bottom chamber for quantitative immunoassays using the AlphaLISA technique to measure cytokines secreted from immune cells. Specifically, we targeted isolation, enrichment, and enumeration of CD14+ monocytes from human blood and perform a quantitative measurement of TNF-α secreted from LPS-stimulated monocytes to establish the diagnosis of immune dysfunctions in sepsis. We envision that our proposed microfluidics-based innovative technology can serve as a comprehensive and standardized immune monitoring platform to define and characterize the “immunotype” of healthy individuals and septic patients, thus leading to interventions that can significantly reduce or eliminate symptoms, side effects, disease progression, recurrence, and ultimately sepsis-associated mortality.

This work was funded, in part, by the National Science Foundation (CMMI 1129611, ECCS-0601237), the MICHNP Pilot Program (CTSA UL1RR024986), NIH R01HL097361, and the department of Mechanical Engineering at the University of Michigan, Ann Arbor.
Single cell suspension culture using polyHEMA coating for anoikis assay and sphere formation
Yu-Chih Chen¹, Patrick Ingram², Xia Lou¹ and Euisik Yoon¹,²

¹Dept. of Electrical Eng. and Computer Science, University of Michigan, Ann Arbor, MI, USA
²Dept. of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA

Cell adhesion to the extracellular matrix is essential in maintaining cellular homeostasis. Disruption of cell attachment leads to anoikis, which triggers the cell death by apoptosis. However, in the metastasis process, tumor cells are required to detach from the ECM and be viable in circulation. Anoikis serves as a natural barrier for metastasis and the ability to evade apoptosis in suspension marks the malignancy of cancer cells. Within metastatic cancer cells, cancer stem cells are tumorigenic and drug-resistant sub-population and are critical in cancer treatment. The ability to form a sphere in suspension environment indicates stemness. Thus, the suspension culture plays a key role in cancer metastasis study. Microfluidic technologies allow single cell analyses for heterogeneous population cell groups, but most platforms are limited to adherent culture. We demonstrated suspension culture by integrating hydrophobic surface inside the microchambers; however, the patterned surface requires expensive DRIE tools and deteriorates the quality of image. In this work, we report a single cell suspension chip which can perform anoikis assay and sphere formation at single cell resolution. The proposed chip uses a hydrodynamic capturing scheme based on difference in flow resistance to guide cell loadings to an exact position in the array of microchambers. PolyHEMA coating is integrated with microfabrication to achieve single cell suspension culture in each microchamber. We performed two sets of experiments: anoikis assay of skov3 cells and sphere formation of SUM159 and MCF-7 cells; and the behavior of each single cell was successfully traced for more than ten days.

This work was funded, in part by Thermo Fisher Scientific Screening Technology Grant under the Center for Chemical Genomics at the Life Sciences Institute at the University of Michigan, and in part by Academic Excellence Alliance Award from KAUST
Single cells to spheres: high throughput microfluidic screening of cancer stem cells  
Patrick Ingram¹*, Yu-Chih Chen²*, Sean McDermott³, Max Wicha³, Euisik Yoon¹,²

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI  
²Department of Electrical Engineering, University of Michigan, Ann Arbor, MI  
³Department of Hematology and Oncology, University of Michigan, Ann Arbor MI  

Recent cancer cell models propose that a small subset of tumor initiating cells (TIC) or cancer “stem-like” cells (CSC) necessary to initiate and sustain cancer growth. They are resistant to traditional therapy and capable of division and differentiation to give rise to a heterogeneous population of tumor cells. Therapeutics which target TIC/CSC have drastically improved patient survival. However, there are several obstacles to the study of TIC/CSC. First, they are very rare, representing typically <5% of cells in cell lines and <1% of cells in tumors. Additionally, there is considerable evidence that several subpopulations of tumor initiating cells may exist within one tumor and their identification would require the use of many cell markers in combination with other identifying characteristics. Traditional methods typically focus on reduction of overall tumor cell number and will therefore miss these rare, transient cells. To address these issues, we have developed and demonstrated microfluidic platforms capable of high efficiency single-cell capture (>90% capture) and long-term suspension culture from single cells. Suspended sphere culture of single cancer cells provides the ability to not only screen cancer heterogeneity at high throughput, but also provides the capability for label-free CSC/TIC drug screening using no external systems. Traditional microfluidic cell culture platforms utilize adherent culture on PDMS and glass substrates, but suspension culture from single cancer cells allow identification of CSC. As such, we have characterized chemical (Poly-HEMA) and mechanical (topographically patterned PDMS) surface modifications for non-adherent culture with great success in multiple breast cancer lines (MCF7 and SUM159).

This work was funded, in part by the Thermo Fisher Scientific Screening Technology Grant under the Center for Chemical Genomics at the Life Sciences Institute at the University of Michigan, in part by Academic Excellence Alliance Award from KAUST, and in part by the National Institute of Health Microfluidics in Biomedical Sciences Training Grant.
Micro-hydraulic structure for high performance biomimetic air flow sensor arrays

Mahdi M. Sadeghi¹, Rebecca L. Peterson¹, Khalil Najafi¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Biomimetic hair-like structures can provide air flow sensing with high accuracy and high resolution. Moreover, hairs with small footprints enable array fabrication to provide redundancy and fault tolerance. Previous works using hairs with piezoresistive or capacitive transduction have very fragile structures that limit the use of the air flow sensors in outside environments. Also, the high accuracy of these sensors is achieved at the expense of dynamic range. Here we introduce a novel micro-hydraulic structure that can significantly improve performance of many MEMS devices. Using this structure we fabricate and test a new type of low-power, accurate and robust flow sensor in which a hair-like appendage is used to translate flow into hydraulic pressure. This pressure is sensed with a capacitor that is integrated with the micro-hydraulic system by which the sensitivity is amplified. The air flow sensor can detect flow speeds ranging from 0.02 m·s⁻¹ to over 15 m·s⁻¹ with a resolution of 2 cm·s⁻¹. Compared to conventional capacitive air flow sensors, this micro-hydraulic sensor expands the full scale range while maintaining the same sensitivity. We have also modified the micro-hydraulic base structure to optimize device performance in the time domain. Our optimized device has shown 400× improvement in the response time of the device and our experimental results indicate a bandwidth of 70 Hz. Recently, we have redesigned the hair and hair-attachment structure. The new design is expected to enhance the sensitivity by approximately 16 ×, and the experimental results are forthcoming.

This work is funded, in part, by MAST Program of the Army Research Lab under Award Number W911NF-08-2-0004.
Aqueous-two phase-mediated wound assay of epithelial cells cultured at air-liquid interface

Josh White¹, Shuichi Takayama¹,²

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²Ulsan National Institute of Science & Technology, School of Nanobiotechnology & Chemical Engineering, Ulsan 689798, South Korea

Lung pathophysiology frequently has some degree of airway epithelial denudation and impaired alveolar-capillary barrier function. Proper re-epithelialization plays a critical role in restoring lung function and preventing the onset of septic shock or chronic parenchymal disorders like pulmonary fibrosis. This re-epithelialization process relies on the migration, spreading, proliferation, and differentiation of nearby epithelial and progenitor cells to re-establish a functional epithelium; in vitro methods to simulate this process include conventional “scratch assays,” circular invasion assays, electrical wounding, and patterning techniques. However, none of these methods incorporate an air-liquid interface (ALI) culture, which is the current gold standard for inducing polarization and creating a more physiologic epithelium. None of the previous wounding methods allow versatile and spatially controllable damage to the epithelium under physiologically relevant culture conditions. For example, cells cultured on soft substrates, or on transwell membranes under ALI culture are difficult to wound reliably. To address these challenges, we apply an aqueous two-phase system to achieve a reproducible in vitro wound healing assay for cells cultured at ALI. This technology has been used previously to spatially pattern reagents and cells because of the preferential partitioning of certain biomolecules and cells to one phase over the other. In this case, we localize trypsin to the dextran phase to selectively detach a circular region of cells from a monolayer cultured on a porous polyester membrane and monitor wound closure of cells cultured at ALI and submersion.

This work was funded, in part, by the National Science Foundation Graduate Student Research Fellowship Program (to JW) under Grant no. DGE 0718128 (ID: 2010101926)
Nanotechnology

Session Chair: Mostafa Bedewy
Anomalous dispersion of hedgehog particles
Joong Hwan Bahng¹, Bongjun Yeom², Siu On Tung³, Ji-Young Kim⁴, Yichun Wang¹, Nicholas Kotov*¹,²,³,⁴

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
³Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI
⁴Department of Material Science and Engineering, University of Michigan, Ann Arbor, MI

Dispersion of hydrophobic particles in water is typically achieved by using surfactants or polymers that “camouflage” hydrophobic surfaces with hydrophilic groups. Aqueous dispersion of hydrophobic particles without the use of any surfactants has both technological and academic significance. In this study, we demonstrate that aqueous dispersion of hydrophobic particles without any “camouflage” is indeed possible with reengineering of the interfacial topography. We sculptured the surface of smooth polystyrene sphere to feature hydrophobic and rigid Zinc Oxide (ZnO) nano-wires, termed the hedgehog particles (HHPs). The HHPs not only dispersed in organic solvents but also in water while retaining hydrophobicity of ZnO spikes in the aqueous environment. We believe that the HHPs form a three-phase shell; radially distal portion occupied with water and the proximal portion filled with air cavity both of which are interdigitated with solid phase ZnO nano-spikes. Such arrangements reduce hydrophobic solid fraction at the HHPs interface, and in conjunction, create large surface area for hydrogen bonding that significantly increase the freedom of water molecules around the interface. The rigid ZnO nano-spikes function to localize and confine entropic loss in the HHP shell, while minimizing the entropic loss of the whole system and enable to circumvent hydrophobic interaction amongst the HHPs.

This work was funded, in part, by ARO/MURI.
Comprehensive non-destructive metrology of carbon nanotube populations for advanced manufacturing processes
Mostafa Bedewy¹ and A. John Hart¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

Nanoscale filaments such as nanotubes and nanowires are promising materials for many applications, in which their unique anisotropic transport properties can be exploited for next-generation electric interconnects, thermal interfaces, sensors, and filtration membranes. In particular, devices that are based on the collective properties of a large number of carbon nanotubes (CNTs) in parallel, highly depend on their size monodispersity, alignment, and packing density. Hence, scaled production of such devices with tailored properties requires an advanced understanding of their population behavior. This is hindered by the lack of characterization techniques capable of inferring the spatiotemporal evolution of CNT alignment and density, as well as probing statistical variations of diameters with high resolution. We have developed a comprehensive non-destructive methodology for studying the population dynamics of vertically aligned CNT forests, synthesized by chemical vapor deposition (CVD). Our approach depends on combining high-resolution spatial mapping of synchrotron X-ray scattering patterns and mass attenuation measurements, with real-time height kinetics of growth. By simultaneously interrogating millions of CNTs, the alignment, density and the statistical distribution of the CNT dimensions, are mapped within forests. In order to elucidate the size-dependent activation-deactivation competition during the successive stages of growth, the time evolution of both number and mass density are precisely mapped as a function of CNT diameter. These findings enable designing dynamic growth recipes, wherein time-varying growth conditions are tuned to produce more uniform, higher quality and denser CNT structures. This methodology can be utilized in the study of population behavior in biofilaments such as microtubules and actin filaments.

This work was funded, in part, by DOE (DE-SC0004927), ONR (N000141010556), and NSF (CMMI-0800213). X-ray scattering at the Cornell High-Energy Synchrotron Source (CHESS), is supported by NSF and NIH (DMR-0225180).
Radiative decay rate enhancement of InGaN site-controlled quantum dots in silver metallic cavity

Brandon Demory\textsuperscript{1}, Chu-Hsiang Teng\textsuperscript{1}, Lei Zhang\textsuperscript{2}, Tyler Hill\textsuperscript{2}, Hui Deng\textsuperscript{2}, and Pei-Cheng Ku\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Physics, University of Michigan, Ann Arbor, MI

The photon is a prime candidate for large capacity, secure data transfer, ranging from chip interconnects to backhaul systems. Applications such as secure communication channels and quantum cryptography require indistinguishable single photon sources (SPS) to detect channel eavesdropping. Currently, InGaN quantum dots show single photon emission potential at higher temperatures, but the long radiative lifetimes and photon energy variations prevent the photons from being indistinguishable by measurement. Shortening the radiative lifetime of the emitted photons below the exciton dephasing time ($T_2$) will make them indistinguishable. Placing the quantum dot in a cavity alters its radiative decay rate by the Purcell Factor of the cavity. The Purcell Factor depends on the dipole orientation, structure geometry, and material composition of the system. Our metallic cavity consists of a dielectric spacer and a silver coating. We used Lumerical FDTD Solutions to simulate the Purcell Factor for our system. Two resonance peaks occur in each case; one dominated by Localized Surface Plasmon (LSP), which leads to strong radiative rate enhancement, and the other dominated by Surface Plasmon (SP) at the dielectric spacer-silver interface, which leads to high metal absorption. By changing the dielectric material, the dielectric’s thickness, and the metal thickness, we are able to tune the wavelength of the LSP peak to 450nm, the emission wavelength of our quantum dots. This work presents the effects of two dielectric spacers, Hafnium Oxide ($\text{Hf}_2\text{O}_2$) and Aluminum Oxide ($\text{Al}_2\text{O}_3$) and the effects of changing the Silver film thickness on the resonance peak location and amplitude.

This work was funded, in part, by [National Science Foundation].
Thin film black body absorbers using carbon nanotube composites
Vikrant J. Gokhale¹, Yu Sui¹, Olga A. Sherendova², Gary E. McGuire², and Mina Rais-Zadeh¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48105, USA
²International Technological Center, Raleigh, NC, 27617, USA

We report on the characterization of near ideal thin-film (≤ 2 μm) optical absorbers comprised of carbon nanotubes in a polymer that can be fabricated on arbitrary surfaces at low processing temperatures. These films can be used as radiation absorbing materials (RAMs) over a wide range of the visible and infrared spectrum, effectively forming a perfectly black coating. Applications include solar energy harvesting, infrared sensor coatings, stealth coatings and thermal diffusers. The dispersed nature of the films results in multiple attritional internal reflections of incident radiation in the film, thus absorbing a wide spectrum of optical radiation almost perfectly. This is similar in concept to cavity black body absorbers (Féry’s black body) that have the ability to absorb radiation perfectly over the entire spectrum. Based on values measured for graphite and carbon-black, carbon is a good intrinsic absorber of infrared radiation. However, the crucial factor that allows such high values of absorption in these films is the mesh-like porous morphology of the films, which can be termed as extrinsic absorption. This is independent or only loosely dependent on the intrinsic absorbing properties of the material used. The extracted real refractive index \(n\) of the fabricated film is close to unity, allowing index matching and low reflectance. The extinction coefficient \(k\) is at least 10 times higher than vertical nanotube absorbers. In conjunction these parameters lead to extremely efficient absorption of radiation over a broad spectrum.

*This work was funded, in part, by the National Science Foundation and Army Research Labs.*
Stretchable conductors from nanoparticle composites with self-organized conductive pathways
Yoonseob Kim¹, Jian Zhu¹, Matthew Di Prima¹, Xianli Su², Jin-Gyu, Kim³, Seung Jo Yoo³, Bongjun Yeom¹, Ctirad Uher², Nicholas A. Kotov¹,*

¹Department of Chemical Engineering, University of Michigan, Ann Arbor, MI, 48109-2136, USA.
²Department of Physics, University of Michigan, Ann Arbor, MI, 48109-1040, USA.
³Division of Electron Microscopic Research, Korea Basic Science Institute (KBSI), 168-148 Gwahangno, Yuseong-gu, Daejeon 305-806, Korea.

Elastic conductors are essential components of next generation electronic devices that can facilitate integration of human-machine interfaces. In the last decade, tremendous research and development efforts have been put into exploring possibilities envisioned from nanoscale building blocks with various polymeric matrixes. Carbon nanotubes (CNTs) have been chosen mainly because of its high aspect ratio that enabled low percolation threshold and good electrical properties during mechanical deformation. Typical stretchable conductors from CNTs, however, have several problems; high quality of composite is not reproducible, metallic conductivity is unlikely, and properties are anisotropic. To overcome those problems, we present a systematic approach making stretchable conductors from extreme content of nanoparticles (NPs) with polymer matrix by layer-by-layer (LBL) assembly technique. To highlight the structural aspects on the properties of composites, layered composites by flocculation were also prepared as counter parts for LBL composites. NPs, in general, might be an inadequate choice as fillers because they do not have as high aspect ratio as CNTs, however specially synthesized NPs with judiciously chosen polymer matrix are expected to have better electromechanical properties. Since dynamics including charge transfer through NPs composite is rarely studied, investigation of those parts will also be one of the core parts of this research project. Scanning electron microscope, transmittance electron microscope, atomic force microscopy, electrical properties measurement system, dynamic mechanical analysis, small-angle X-ray scattering were performed to analyze properties of nanocomposites.

This work was funded, in part, by STX foundation, Seoul, Korea, and US Air Force Office of Scientific Research.
Targeting hepatic cancer cells with pegylated dendrimers displaying n-acetylgalactosamine and SP94 peptide ligands

Sibu Kuruvilla\(^1\), Gopi Tiruchinapally\(^2\), Scott Medina\(^2\), and Mohamed E. H. ElSayed\(^{2,3}\)

\(^1\)Department of Materials Science & Engineering, University of Michigan, Ann Arbor, MI
\(^2\)Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\(^3\)Macromolecular Science & Engineering Program, University of Michigan, Ann Arbor, MI

We report the synthesis of PEGylated G5 particles where poly(ethylene glycol) (PEG) chains are conjugated to the primary amine surface groups of generation 5 (G5) of poly(amidoamine) (PAMAM) dendrimers via acid-labile cis-aconityl linkages (c). The free ends of the PEG “brush” were functionalized with N-acetylgalactosamine (NAcGal) or the SP94 peptide to function as hepatic cancer cell (HCC) targeting ligands. We hypothesized that these NAcGal- and SP94-targeted PEGylated G5 particles would be internalized by hepatic cancer cells via receptor-mediated endocytosis allowing the delivery of chemotherapeutic drugs selectively into the cytoplasm of hepatic cancer cells. We investigated the internalization of these targeted particles by HCC and normal hepatocytes as a function of ligand composition (NAcGal sugar versus SP94 peptide), sugar conformation (α versus β), concentration, and incubation time. We also evaluated the opsonization of different targeted particles and their uptake by liver macrophages (Kupffer cells). Flow cytometry results show that the β conformation of NAcGal sugar molecules led to a 31-fold increase in internalization of G5-(cPEG[NAcGal\(β\)]) particles into HCC compared to NAcGal\(α\)-targeted particles, and they were also more rapidly internalized into HCC compared to the SP94-targeted G5-(cPEG[SP94]) particles. Further, G5-(cPEG[NAcGal\(β\)]) particles showed up to a 50-fold enhancement in affinity for HCC compared to normal hepatocytes. Results also show that G5-(cPEG[NAcGal\(β\)]) particles exhibited limited opsonization when incubated with model proteins, reducing their phagocytosis into liver macrophages by 17-fold compared to other particles. These results collectively show that G5-(cPEG[NAcGal\(β\)]) particles are promising carriers for targeted delivery of anticancer drugs to hepatic cancer cells.

*This work was funded, in part, by the NSF CAREER Award (M. ElSayed), the Coulter Foundation Translational Research Partnership in Biomedical Engineering Award (M. ElSayed), and the Rackham Merit Fellowship (S. Kuruvilla).*
Development of “smart” particles for silencing Bcl-2 expression in head and neck cancer cells

Yen-Ling Lin¹, Yasemin Y. Durmaz¹, Jacques Nör², and Mohamed E.H. ElSayed¹,³

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²School of Dentistry, University of Michigan, Ann Arbor, MI
³Macromolecular Science & Engineering Program, University of Michigan, Ann Arbor, MI

Bcl-2 is an anti-apoptotic protein that is over-expressed in many human cancer cells and has been linked to increased resistance to radio- and chemo-therapy in head and neck squamous cell carcinoma. These studies suggest that inhibition of anti-apoptotic Bcl-2 expression using small interfering RNA (siRNA) is a viable strategy to suppress tumor growth and induce cancer cell death. However, delivery of siRNA molecules selectively into the cytoplasm of cancer cells remains a significant challenge due to their entrapment in the endosomal/lysosomal trafficking pathway. Therefore, we have designed and synthesized new degradable, pH-sensitive, membrane-destabilizing particles that can shuttle a large dose of anti-Bcl-2 siRNA molecules past the endosomal membrane and into the cytoplasm of head and neck cancer cells. Specifically, we grafted amphiphilic P(HMA-co-DMAEMA-co-TMAEMA) copolymers from the secondary face of β-cyclodextrin (β-CD) via acid-labile hydrazine linkages forming star-shaped, pH-sensitive β-CD-based polymers that complex siRNA molecules via electrostatic interaction forming “smart” particles, which remain stable at physiologic pH but hydrolyze into membrane-active fragments that disrupt the endosomal membrane and release the nucleic acid cargo into the cytoplasm when exposed to acidic endosomal pH gradients. We evaluated the ability of these “smart” particles to deliver anti-Bcl-2 siRNA molecules past the endosomal membrane and into the cytoplasm of head and neck cancer cells to achieve functional Bcl-2 knockdown at both the mRNA and protein levels. We also evaluated the effect of combining Bcl-2 knockdown using “smart” particles loaded with anti-Bcl-2 siRNA molecules with a BH3-mimetic drug, AT-101, on the cancer cell survival.
Multicompartmental polymer nanocarriers for cancer theranostics
Asish C Misra¹, Tae-Hong Park², Srijanani Bhaskar³, Nicholas Clay², Jaewon Yoon³, Sahar Rahmani¹, Joerg Lahann¹,²,³

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
³Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI

There is great potential for polymer micro- and nano-carriers in biomedical applications such as tissue engineering or drug delivery. However, while such technologies are hypothesized in some case to increase efficacy and potency of small molecule drugs this goal has not been realized. There are many barriers to effective therapy caused by both physiological and pathophysiological processes. Therefore, multifunctional carriers capable of addressing multiple challenges are required for effective therapy. Electrohydrodynamic co-jetting is a technique that may allow for the manufacturing of such particles. Here we propose to develop several particle systems using the co-jetting technique to address the challenge of developing carriers that can cope with these barriers to effective therapy.
Higher-order adaptive finite-element methods for Kohn-Sham density functional theory
Phani Motamarri¹, Vikram Gavini¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

Defects in solids influence many macroscopic properties like fracture toughness, electrical conductivity, optical, magnetic properties etc. A mathematical model which accurately describes defects must incorporate physics at multiple length scales from quantum mechanical scale to continuum scale. This requires the capability of simulating thousands of atoms in a non-periodic setting which is often beyond the current capability of electronic structure codes using density-functional theory. In this work, we present an efficient computational approach to perform real-space electronic structure calculations using an adaptive higher-order finite-element discretization of Kohn-Sham density-functional theory (DFT). To this end, we develop an a-priori mesh adaption technique and further propose an efficient solution strategy for solving the discrete eigenvalue problem by using spectral finite-elements in conjunction with Gauss-Lobatto quadrature, and Chebyshev acceleration techniques. Using the proposed solution procedure, staggering computational savings—of the order of 1000-fold—can be realized, by using higher-order finite-element discretizations. A comparative study of the computational efficiency of the proposed higher-order finite-element discretizations suggests that the performance of finite-element basis is competing with commercially available plane-wave codes. Further, we demonstrate the capability of the proposed approach to compute the electronic structure of materials systems containing a few thousand atoms using modest computational resources, and good scalability of the present implementation up to a few hundred processors.

This work was funded, in part, by Army Research Labs.
Identifying the primary causes of variability in lab-scale growth of carbon nanotube films

C. Ryan Oliver¹, Erik Polsen¹, Eric R. Meshot¹, Sameh Tawfick¹, Sei Jin Park¹, and A. John Hart¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI. 48109, USA

While many promising applications have been demonstrated for vertically aligned CNT forests, lack of consistency in results (e.g., CNT quality, height, and density) admittedly hinders knowledge transfer and commercialization. For example, it is well known that CNT growth can be influenced by small concentrations of water vapor, carbon deposits on the reactor wall, and run-to-run variations in pressure within the reaction chamber. However, even when these parameters are controlled during synthesis, we found that variations in ambient lab conditions can overwhelm attempts to perform parametric optimization studies. We present a comprehensive study, based on standardization of a CNT forest growth procedure, which identifies primary sources of variation in lab-scale growth of CNT forests. The chemical vapor deposition (CVD) recipe (time, temperature, gas flow rates) was held constant for this study, while we varied other variables related to the furnace configuration and experimental procedure. Statistical analysis of over 280 samples showed that ambient humidity, barometric pressure, and sample location in the CVD environment contribute significantly to run-to-run variation, whereas sample position on the wafer, and catalyst storage conditions do not cause variation. Based on these findings, we recommend a standard procedure that can be used as a baseline to reduce variation for atmospheric pressure thermal CVD methods, and to speed transfer of knowledge between laboratories and industry. Initial results using this approach reduce variation in CNT forest height by more than 50%.
Measurement of carbon nanotube micropillar density by optical absorption and observation of size-dependent density variations

Sei Jin Park¹, Aaron J. Schmidt², A. John Hart³

¹Mechanosynthesis Group, Department of Mechanical Engineering, University of Michigan, 2350 Hayward Street, Ann Arbor, Michigan 48109
²The Nano Heat Transfer Lab, Department of Mechanical Engineering, Boston University, 110 Cummington Street, Boston, Massachusetts 02215

Engineering the packing density of CNT forest microstructures is vital to applications such as electrical interconnects, micro-contact probes, and thermal interface materials. For relatively large CNT forests (~1x1 cm, >100μm thickness), weight and volume can be used as a measure of bulk density. However, this is not suitable for smaller samples, including individual microstructures, and moreover does not enable mapping of spatial variations within the forest. We demonstrate that the packing density of CNTs within individual microstructures can be measured by optical absorption, with spatial resolution equaling the size of the focused spot. For this, a custom optical setup was built to measure the transmission of focused laser beam (632nm, spot size 40μm) through CNT microstructures. The transmittance was correlated with the thickness of the CNT microstructures by Beer-Lambert Law to calculate the absorption coefficient. We reveal that the density of CNT microstructures grown by CVD can depend on their size, and that the overall density of arrays of microstructures is affected significantly by run-to-run process variations. Further, we use the technique to quantify the density increase of CNTs due to capillary densification. Our work demonstrates a useful and accessible metrology technique for CNTs in future microfabrication processes, and will enable direct correlation of density to important properties such as stiffness and electrical conductivity.

This work was funded, in part, by University of Michigan.
Convective assembly of catalyst nanoparticle arrays for vertically aligned carbon nanotube growth with decoupled diameter and density control

Erik Polsen¹, Mostafa Bedewy¹, A. John Hart¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

The widespread potential applications of vertically aligned CNT forests have stimulated recent work on continuous-feed and large-area CVD growth methods; however, to enable a complete manufacturing process, improved control and scalability of catalyst deposition is needed. Most often, catalyst films are deposited by evaporation or sputtering, and precise control of the film thickness and annealing parameters is employed to tune the diameter and packing density of CNT forests. Unfortunately, vacuum deposition methods are unlikely to meet the cost metrics for large-area CNT forest production; and the monodispersity and packing density of CNTs is limited by thin film agglomeration mechanics. In an effort to overcome these limitations, we demonstrate the continuous deposition of well-defined nanoparticle monolayers for CNT growth, by convective self-assembly. Catalyst is deposited from a solution of commercially available iron oxide nanoparticles, by translating a meniscus of the solution over the substrate using a blade edge. We demonstrate a priori control of CNT diameter and packing density, based on design of the particle solution and tuning of the assembly parameters (speed, substrate temperature). Further, we study the relationship between the size and arrangement of the catalyst particles, and the CNT morphology and packing density, leading to insights on what limits the traditionally low packing density of CNT forests. This novel process shows promise to approach ultimate limits of CNT forest density, and to assemble catalyst arrays at high speeds under ambient conditions.

This work was funded, in part, by the Nanomanufacturing program of the National Science Foundation (CMMI-0927634); the Scalable Nanomanufacturing Program of the National Science Foundation (DMR-1120187); the Office of Naval Research (N0001411M0217) via a subcontract to the from Absolute Nano, LLC to the University of Michigan; and the DoD, Air Force Office of Scientific Research, National Defense Science and Engineering Graduate (NDSEG) Fellowship, 32 CFR 168a.
Directed self-assembly of rods
Aayush A. Shah¹, Benjamin Schultz², Charles W. Monroe³, Sharon C. Glotzer¹,²,³, and Michael J. Solomon³.

¹Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI
²Department of Physics, University of Michigan, Ann Arbor, MI
³Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

We report the use of an applied electric field to produce anisotropic orientational order in micron-sized Brownian colloidal rods. The suspensions, because of their slow Brownian dynamics, undergo equilibrium self-assembly only on long time scales. Application of an electric field significantly accelerates the kinetics of assembly. The spatial and orientational structure of the assemblies is imaged in three dimensions using confocal microscopy and quantified by means of image processing. We analyze our results in terms of the underlying electrokinetics of the system, as well as connecting the observed field-induced orientational order to the equilibrium isotropic-nematic transition predicted for repulsive rods. The results show a change from isotropic to nematic orientation followed by a transition from mobile to glassy dynamics as the Direct-Current (DC) electric field strength across the homogeneous rods is increased. We also report the formation of a Body-Centered Tetragonal crystal structure for these assembled rods. Finally, we synthesize patchy rods and show that this anisotropy in the pair-potential gives rise to new possibility for the characterization of self-assembly structures

This work was funded by Army Research Office, Multiuniversity Research Initiative (ARO-MURI).
Linewidth reduction of site-controlled InGaN quantum dots by surface passivation

Chu-Hsiang Teng, Lei Zhang, Hui Deng, Pei-Cheng Ku

1Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
2Department of Physics, University of Michigan, Ann Arbor, MI

Indium gallium nitride (InGaN) semiconductor quantum dots are an attractive candidate for scalable room temperature quantum photonics applications owing to the large exciton binding energy and large oscillation strength. Previously, we reported single photon emission from site-controlled InGaN dot-in-wire structures fabricated by e-beam lithography and dry etching. However, large homogeneous linewidth and abnormally long radiative lifetime were thought to be linked to the nearby charge centers. These charge centers can limit the excitation rate of excitons in the quantum dots, result in spectral diffusion, and contribute to the excessive non-radiative recombinations at high temperature. The linewidth of a single quantum dot is on the order of tens of meV at low temperature and increases and saturates at 150 K. Moreover, time-resolved PL rendered 3.5 ns lifetime, while the second order correlation measurement showed 200 ps lifetime. The inconsistency further confirmed the presence of surface charge centers acting as a carrier reservoir. In this work, approaches to reducing InGaN quantum dot emission linewidth were investigated. These include the passivation of surface states (mainly nitrogen vacancies) and passivation of InGaN active region against oxidation. Nitrogen vacancies were successfully passivated by ammonium sulfide ((NH4)2Sx) treatment, and the emission linewidth of a single quantum dot was reduced by 5 meV. Furthermore, the linewidth broadening with an increasing temperature was suppressed in the temperature range from 9 K to 95 K in this study. Satellite emission peak believed to be associated with the nitrogen vacancy was observed for un-passivated quantum dots. The satellite peak was 55 ~ 80 meV away from the main InGaN emission peak and was eliminated after sulfide passivation.
Terahertz power enhancement using plasmonic photomixers
Shang-Hua Yang$^1$ and Mona Jarrahi$^1$

$^1$Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109, USA

Even though the terahertz spectrum is well suited for chemical identification, material characterization, biological sensing and medical imaging, practical development of these applications has been hindered by the attributes of terahertz sources, namely low output power and poor efficiency. Here, we report a high-performance photomixer based terahertz source incorporating nano-plasmonic apertures to achieve orders of magnitude higher power levels compared to the state-of-the-art. The use of nano-plasmonic apertures as a part of the photomixer contact electrodes manipulates the distribution of the photo-generated carriers and accumulates a large number of photo-generated carriers in close proximity to the contact electrodes, such that they can be collected within a sub-picosecond timescale. Another important attribute of plasmonic photomixers is that they accommodate large device active areas without a considerable increase in the parasitic loading to the terahertz radiating antenna. Utilizing large device active areas enables mitigating the carrier screening effect and thermal breakdown, which are the ultimate limitations for the maximum radiation power from conventional photomixers. In order to maximize optical-to-terahertz conversion efficiency, we have designed high aspect-ratio nano-plasmonic apertures, which can collect the majority of the photo-generated carriers within a sub-picosecond time-scale. Our preliminarily analytical and numerical modeling result shows that the performance of the nano-plasmonic apertures is highly geometry dependent and, hence, a highly robust nanofabrication process becomes crucial for realizing high-power plasmonic photomixers. The developed nano-fabrication process for implementing the designed high aspect-ratio plasmonic apertures and experimental characterization of the implemented prototypes are analyzed and presented.
Determining the shape of single, native proteins

Erik C. Yusko, \(^1\) Brandon R. Bruhn, \(^1\) Ryan C. Rollings, \(^2\) Jial Li, \(^2\) David Sept\(^1,3\), Michael Mayer\(^1,4\)

\(^1\)Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\(^2\)Department of Physics, University of Arkansas, Fayetteville, AR
\(^3\)Center for Computational Medicine and Biology, University of Michigan, Ann Arbor, MI
\(^4\)Department of Chemical Engineering, University of Michigan, Ann Arbor, MI

Recording ionic current through electrolyte-filled nanopores during the passage of proteins is an emerging technique for characterizing unmodified proteins in their native, aqueous environment. Here, we demonstrate the use of lipid-bilayer coated nanopores for determining the shape and volume of single, spherical and non-spherical proteins that are anchored to mobile lipids in the coating. This work shows that individual resistive-pulses can also be used to determine the rotational diffusion coefficient and dipole moment of non-spherical proteins while in the nanopore. Moreover, this method has the potential to detect transient changes in the conformation of flexible proteins (e.g. an IgG antibody). This work extends the power of nanopores for characterizing proteins by adding the parameters of shape, volume, rotational diffusion coefficient, and dipole moment of non-spherical proteins to those that can already be determined in a single experiment such as the volume of spherical proteins, charge, and affinity for a ligand.

This work was funded, in part, by the National Institutes of Health (M.M., grant no. 1R01GM081705), the National Human Genome Research Institute (J.L., grant no. HG003290 and HG004776). E.C.Y. acknowledges a fellowship from the Graduate Assistance in Areas of National Need program from the Dept. of Education and a Rackham Pre-Doctoral Fellowship from the University of Michigan. B.R.B. acknowledges a fellowship from the Microfluidics in Biomedical Sciences Training Program from the NIH and NIBIB.
Naval Architecture and Marine Engineering

Session Chair: Thomas McKenney
A heuristic approach to multi-discipline design optimization using hierarchical fuzzy logic controllers
Brian Cuneo

1Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

During early stages of design of large scale engineering systems, such as ships, competing objectives of multiple discipline analyzers must be taken into account. Currently, tools such as Multidisciplinary Design Optimization (MDO) provide an automated method for analyzing tradeoffs between competing discipline design objectives. While automated design methods are useful in the design world, results are dependent on the fidelity of models used to represent the system. For design spaces where computationally expensive high fidelity tools are feasible, current MDO methods provide an efficient method of exploring the design space. For large complex design spaces, a more heuristic approach is desirable during early stages of design to identify preferred areas of the design space for further evaluation. A new method of MDO is proposed which attempts to emulate the intuition and intent of a human engineer when examining low fidelity models in early stages of design. The method uses the ideas of managing tradeoffs and modeling discipline interactions from MDO, and adds knowledge to the system that allows for decisions to be made on early design space models more like a human designer. Hierarchical fuzzy logic controllers have been successfully used to emulate the decision making of human operators in complex system control. The proposed method may provide a more heuristic approach to automated early stage design by extending the ideas of hierarchical fuzzy logic controllers to the design process.

This work was funded, in part, by The Office of Naval Research.
Dynamic control of a closed two-stage queueing network for the ship outfitting process
Fang Dong¹.

¹Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI

As an important part of shipbuilding, outfitting can represent a major portion of the material cost as well as the construction time of a vessel. However, due to disturbances caused by unexpected delays, system variations, and technological constraints, scheduling of outfitting processes is complex and can lead to major construction delays. To improve the shipbuilding system efficiency in the presence of variation, a two-stage strategic level outfitting planning model has been developed. The results of the model provide the optimal percentage of outfitting work that should be completed at each stage given the introduction of variation. To control the system, a Markov Decision Process model is developed. The numerical results show that a threshold type control policy has the optimality to minimize the cost. Several heuristic control policies are applied in simulation, including the Longest Queue policy, Threshold policy, and the Strict Priority policy. This dynamic queueing model provides an efficient control policy for doing outfitting to each block given different circumstances. The model presented can be used as a benchmark for current ship outfitting management decisions.
The structure of ship design: looking for insights with a network theoretic approach

Morgan C. Parker¹, David J. Singer¹

¹Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

Engineers have historically tried to deal with complexity, those interactions they do not fully understand or cannot anticipate, by handling design in a systematic way, also known as a design process or methodology. By stepping through each decision in a systematic fashion, accumulating knowledge and expertise along the way, engineers hope to arrive at a feasible solution that is understood well enough to warrant the risk of production. The design process itself is complex, and at its conclusion has elucidated a network of ideas whose emergent feature is the design. This research is predicated on the idea that this network of ideas exists independently and prior to the design, and an attempt to understand the network can address complexity directly. This research is not advocating a new design methodology, but investigating the fundamental relationships between the components of design, trying to understand the product without having designed it. Suitably, network theory is the method chosen for this research, mapping the topology of the solution space of a ship design, including variables, functions of variables, requirements etc. using existing theory and derived variations of it. This poster will present a brief background on network theory, other examples of its application beyond the social sciences, and specific results from the current research. A simple network model of a common ship design template will be presented. Metrics derived from this model will be compared with the results of classic optimization, providing insight into how network methods could predict the topology of solution spaces.

This work was funded, in part, by the Department of Defense through the Science, Mathematics and Research for Transformation (SMART) scholarship program and the Naval Engineering Education Center (NEEC).
A novel structural complexity metric and its impact on structural cost estimating and weight

Douglas Rigterink¹

¹Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

A new metric for determining build complexity considering factors such as access for welding, bracketing, steps in plate thickness and related producibility concerns is introduced. The new metric is applied to the creation of stiffened panel structures. Using a multi-objective genetic algorithm, the Pareto trade space between traditional cost estimates, weight, and the new complexity metrics is developed. By comparing designs along the Pareto front, the effect of reducing complexity has on estimated production cost is further explored. In general, it is shown that traditional costing methods and the new producibility metric are in competition and there is a large tradeoff. It is believed that this metric can be expanded beyond stiffened panels into all areas of the hull structure.

This work was funded, in part, by the Department of Defense through the Science, Mathematics and Research for Transformation (SMART) scholarship program and the Naval Engineering Education Center (NEEC).
Large-scale surface effect ship bow seal experiments
Andrew D. Wiggins¹, Steven F. Zalek¹, Marc Perlin¹, Steven L. Ceccio¹, Lawrence J. Doctors², Robert J. Etter³

¹Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI, USA
²School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, AUS
³Naval Surface Warfare Center Carderock Division, West Bethesda, MD, USA

The bow seal system on surface-effect ships (SES) consists of a series of open-ended fabric cylinders (“fingers”) that contact the free surface and, when inflated, form a compliant pressure barrier. The response characteristics are of practical interest due to unacceptable wear rates on seal components and difficulties in predicting seal performance. The objectives of this research are to investigate the physics of SES bow seals through large-scale physical experiments and to lay the groundwork for improved seal design tools. The experimental approach overcomes scaling problems that limited previous SES seal studies and enables the detailed measurements required to characterize bow seal response. Experiments were conducted at the U.S. Navy's Large Cavitation Channel (2011-2012) using a newly developed seal testing platform, 8 meters in length. Three seal geometries and two seal materials were tested at pressures from 0-3000 Pa and velocities to 8m/s. The experiments show that the seal cross-flow response is characterized by stable and unstable behavior, marked by the presence of travelling waves and mode-cycling. Based on high-speed video and data from a 3-d motion capture system, a classification of the primary seal response regimes is proposed. Scaling arguments are used to show that the cross-flow wavelength scales with velocity ($\lambda_{cf} \sim U^{0.5}$) and wetted length ($\lambda_{cf} \sim l_w^{0.25}$) consistent with experimental results. These results demonstrate a feasible system for investigating seal physics within a free surface water channel and begin to identify important features of bow seal response.

This work was funded in part by the Office of Naval Research
Offshore wind turbine interaction with surface ice in the great lakes

Bingbin Yu¹, Dale Karr¹

¹Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

Offshore wind energy has been attracting more attention these days since it has minimal environmental effects and the best resources are reasonably well located relative to the centers of electricity demand. As of 2012, no offshore wind turbines have been installed in U.S. waters. However, there are projects under development in wind-rich areas along the East Coast, Pacific coast and in the Great Lakes. In this research, one important technical challenge for developing offshore wind turbines in the Great Lakes is addressed: the presence of ice. In order to model the ice load and simulate its effect on wind turbine structures, we have augmented an existing Computer-Aided Engineering tool, FAST. We have developed an ice module in FAST to represent interaction of ice and offshore wind turbines. This ice module includes multiple ice-structure interaction models. The differences between the models depend on ice failure modes and structure characteristics. Also, as an important input for determining ice loads, ice thickness is established, based on the air temperature data over Lake Huron. After comparing the prediction result to ice thickness data measured on Lake Huron, several plans are made to improve the ice growth prediction model.

This work was funded by Department of Energy.
Nuclear Science, Energy, and Engineering

Session Chair: Bruce Pierson
Role of helium in swelling behavior and precipitate formation in ion irradiated HT9 steel

Elizabeth M. Beckett\textsuperscript{1}, Gary S. Was\textsuperscript{1}, Zhijie Jiao\textsuperscript{1}, Kai Sun\textsuperscript{2}

\textsuperscript{1}Department of Nuclear Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

Determining the microstructural behavior of ferritic-martensitic alloys is important for predicting the safety and structural integrity of fast spectrum reactors. Of particular interest is the phenomenon of radiation-induced void swelling, which could potentially cause dimensional changes in key structural components in reactors. Irradiations performed with heavy ions can be used to model neutron irradiations at an accelerated dose rate and are beneficial in terms of reduced time required and greater temperature control than reactor irradiations. Self-ion irradiation experiments have been performed on ferritic-martensitic alloy HT9 to determine swelling behavior at 440°C to doses of 200 dpa and above using two different helium implant states. Irradiations were performed on both helium implanted and unimplanted samples using raster scanning on a Tandetron accelerator at the Michigan Ion Beam Lab. The effects of helium pre-implantation on bulk swelling were determined by examining the void distribution using transmission electron microscopy (TEM) and in samples implanted with 0, 10 and 100 atom parts per million (appm) helium. Additionally, atom probe tomography (APT) was used to examine the effect of helium on precipitate formation. Helium implantation was found to be required for void formation in all samples irradiated, and increased helium increased the void number density.

This work was funded, in part, by TerraPower, LLC and the National Science Foundation.
Characterization of the CLYC detector for neutron and photon detection

M. M. Bourne¹, C. M. Mussi, E. C. Miller, S. D. Clarke, S. A. Pozzi, and A. Gueorguiev

¹Department of Nuclear Engineering & Radiological Sciences, University of Michigan, Ann Arbor, MI 48109

Cs₂LiYCl₆ (CLYC) is an exciting new detector capable of gamma-ray spectroscopy and neutron capture. Before it can be applied to nuclear nonproliferation and other applications, it needs detailed characterization. In particular, its detection efficiency, response function, and energy resolution for photons and neutrons need to be understood. The goal of this work is to develop an accurate model that will predict the CLYC detector response to various photon and neutron sources. MCNPX-PoliMi, a variation of the MCNPX code, was used to model separate measurements of $^{137}$Cs and $^{241}$AmBe taken with a CLYC detector. MPPost, a specialized FORTRAN post-processing script, was then used to determine the pulse height distribution recorded by the detector for each measurement and apply energy resolution. Direct comparisons of the simulated and measured detector response show promising agreement in the Compton continua, though the simulation currently overpredicts the measured $^{137}$Cs photopeak efficiency by about 30% and the neutron capture efficiency by over a factor of 2.
Fast neutron multiplicity measurements with organic-scintillators for nuclear safeguards applications

Jennifer L. Dolan\(^1\), Eric C. Miller\(^1\), Alice Tomanin\(^2\), Andreas Enqvist\(^1\), Marek Flaska\(^1\), Shaun D. Clarke\(^1\), Sara A. Pozzi\(^1\), Paolo Peerani\(^2\), and David L. Chichester\(^3\)

\(^1\) Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI 48109, USA
\(^2\) European Commission, Joint Research Centre, IPSC, Ispra 21020, Italy
\(^3\) Idaho National Laboratory, Idaho Falls, ID 83403

Nuclear safeguards are defined as the efforts to prevent diversion of fissile material. Given the number of nuclear facilities and current proliferation threats across the world, new technologies are needed to maintain successful international safeguards efforts. The desired increase in fuel reprocessing also encourages innovation in new safeguards techniques to minimize the associated nonproliferation risks. The International Atomic Energy Agency has asked for active research efforts in the development of new safeguards systems. Many safeguards measurement systems currently used at nuclear facilities rely on He-3 detectors and multiplicity-type measurements to verify quantities of special nuclear material. Due to resource shortages, alternatives to these existing He-3 based systems are being sought. Work is also underway to broaden the capabilities of these measurement systems in order to improve current multiplicity analysis. Liquid scintillators are a promising candidate for innovative measurement systems. Measurements were performed on nuclear materials at the Joint Research Centre in Italy. A University of Michigan developed measurement system was used to measure well-defined nuclear material with various shielding configurations. The data analysis exhibits the potential use of liquid scintillators in advanced neutron multiplicity systems. Additionally, this research illustrates the use of Monte Carlo simulations (MCNPX-PoliMi) in nuclear safeguards advancement.

\textit{This research was funded by the U.S. Department of Energy Office of Nuclear Energy and the Material Protection Accountability and Control Technologies Program. Idaho National Laboratory is operated for the U.S. Department of Energy by Battelle Energy Alliance under DOE contract DE-AC07-05-ID14517 This research was performed under the Nuclear Forensics Graduate Fellowship Program, which is sponsored by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office and the U.S. Department of Defense, Defense Threat Reduction Agency.}
Validation of RANS turbulence models against mixing experiments at the FLORIS test facility

Timothy P. Grunloh¹, Victor Petrov¹, Annalisa Manera¹, Davide Bertolotto², Horst-Michael Prasser³,²

¹Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI
²Alstrom Power, Baden, Switzerland
³Laboratory of Energy Systems, ETH-Zurich, Zurich, Switzerland
⁴Laboratory of Thermal-Hydraulics, Paul Scherrer Institute, Villigen, Switzerland

The experimental facility FLORIS (Flow circulation in the Lower plenum and RISer) was built at the Paul Scherrer Institute to investigate mixing in a simplified model of a Boiling Water Reactor (BWR) pressure vessel. The facility consists of a scaled-down (1:10) transparent, two-dimensional vertical section of the downcomer, lower plenum, and core regions of a BWR. The two jet pumps are connected each to a recirculation loop driven by a pump. The internal walls of the FLORIS two-dimensional section are equipped with a wire-mesh sensor featuring 112x64 measuring electrodes. The sensor allows for detailed measurement of the time-dependent mixing field in the lower and upper plena and core region of the test section. A saline water solution injected in one of the two loops is used as tracer. Steady state experiments have been carried out in symmetric (both recirculation pumps operating) and asymmetric (only one operating pump) conditions. Transient experiments involving a recirculation pump start-up and shut-down have been performed as well. The experiments have been simulated using the computational fluid dynamics (CFD) code STAR-CCM+ and a detailed comparison with the time-dependent, two-dimensional distribution of the tracer in the test section is presented. Both isotropic and anisotropic RANS turbulence models have been tested. It is found that recirculation zones forming in the lower plenum are particularly challenging for RANS models.

This work was funded, in part, by Nuclear Engineering University Programs (NEUP) and the Nuclear Regulatory Commission (NRC).
Development of a predictive hybrid model for ion-radiation induced nano-structures
Efrain Hernandez-Rivera

1Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

There is a current trend to move towards smaller-dimensional scales-- the "pursuit of the nano." This is especially true in the semiconductor industry, where quantum confinement characteristics promise great improvements in the material's electric and optical properties. Ion beam irradiation of semiconductors is a promising technique for the development of these desired nanostructures. We are currently developing a hybrid model which couples a statistical (kinetic Monte Carlo method) and a deterministic (Cahn-Hilliard and Allen-Cahn equation systems) scheme. Essentially, the kMC scheme would work as the stochastic event-selection mechanism, while the deterministic equations track the different fields (composition and phase in our case). We need both field equations since the composition field is conserved and the phase field is not conserved. Finite difference methods will be employed to approximately solve these equations. This model is expected to properly simulate the formation of quantum dots and generation of nano-porous structures.
Development of a discrimination ratio for the differential die-away self-interrogation system
Alexis C. Kaplan\textsuperscript{1}, Stephen J. Tobin\textsuperscript{2}, Anthony Belian\textsuperscript{2}, Sara Pozzi\textsuperscript{1}

\textsuperscript{1}Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Los Alamos National Laboratory, Los Alamos, NM

Differential Die-away Self-Interrogation (DDSI) is a non-destructive spent fuel assay system developed at Los Alamos National Laboratory. DDSI uses neutrons emitted from induced fission of $^{239}\text{Pu}$ and $^{235}\text{U}$ to determine fissile mass and partial defect scenarios in which fuel pins containing special nuclear material are diverted. Fission is induced by neutrons from spontaneous fission of $^{244}\text{Cm}$ within the assembly. The system in its current design can measure fissile mass in the assembly including $^{239}\text{Pu}$, $^{241}\text{Pu}$, and $^{235}\text{U}$. Ideally, the system should also be able to differentiate between plutonium and uranium. A feasibility study has been conducted to determine whether a discrimination ratio (DR) can reflect relative quantities of Pu and U in a measured assembly. The concept for developing this ratio is based on a $0.3\text{-eV}$ resonance in the induced fission cross-section of $^{239}\text{Pu}$ which could provide a unique time signature, allowing for differentiation between $^{239}\text{Pu}$ and $^{235}\text{U}$. To determine the optimal time and signature for the DR, analysis of the time spectra was performed using simulated He-3 detectors. The discrimination ratio utilizes the die-away time and doubles rate in the chosen time gates. The result was a ratio that increased in a smooth curve with increasing Pu fraction in the assembly, reflecting the strong influence of the $0.3\text{-eV}$ resonance.

This research was performed under the Nuclear Forensics Graduate Fellowship Program, which is sponsored by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office and the U.S. Department of Defense, Defense Threat Reduction Agency. This research was also funded by Los Alamos National Laboratory, NNSA
The local importance function transform (LIFT) method revisited
Kendra P. Keady¹ and Edward W. Larsen¹

¹Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

Radiation transport problems of interest to national security often involve large, heterogeneous three-dimensional spatial domains with small source and/or detector regions (e.g. portal monitoring, urban search scenarios). Simulating these realistic problems with traditional Monte Carlo methods is a very computationally expensive process. Deterministic simulations, while less expensive, require substantial discretization and are prone to numerical error. As a result of these issues, a number of hybrid methods have been developed which seek to combine the best features of Monte Carlo and deterministic methods. The result is a transport simulation that is both more efficient and more accurate than either method alone. In this research, we investigate further improvements to the hybrid method LIFT, which was originally developed at the University of Michigan by Turner and Larsen. LIFT processes information from an inexpensive deterministic adjoint solution in a unique way to bias the physics of a subsequent Monte Carlo simulation. The weights of the Monte Carlo particles are adjusted appropriately to ensure that the solution reproduces the behavior of the real physical system. Our current work focuses on the development of alternate mathematical expressions for the local physics biasing parameter, as well as the derivation of a LIFT-specific anisotropic scattering treatment. The ultimate goal of this work is to identify modifications to the original LIFT method which can be implemented in a production-quality code for use in the field.

This work was funded in part by the National Nuclear Security Administration (NNSA) Office of Defense Nuclear Nonproliferation.
Parallel algorithm for whole-core 3-D neutron transport calculations using the method of characteristics

Brendan Kochunas\(^1\) and Prof. Tom Downar\(^1\)

\(^1\)Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

The field of Light Water Reactor (LWR) analysis has recently made efforts to significantly advance their simulation capability made possible by state of the art petascale super computers. The principal economic motivation for improved reactor core calculations has been to increase reactor power density and operational flexibility without compromising reactor safety. Full core 3-D transport calculations make this possible by reducing the uncertainty of computed solutions and employing first-principle based methods. In this work, a new parallel algorithm for the solution of the Boltzmann transport equation by the Method of Characteristics (MOC) is developed, verified, and analyzed. The algorithm decomposes the neutron flux in the space, energy, and angle phase spaces, as well as along the discrete characteristic rays. The correctness of the method is verified using the Takeda 3-D Transport Numerical Benchmark. Results compared to within 40 pcm of the reference which had a statistical uncertainty of 60 pcm. An initial study on the computational performance was also done to assess the parallel efficiency of the algorithm. The overall observed strong scaling efficiency of the algorithm is estimated at 52%. Suggested improvements to the parallel decomposition are presented and demonstrated to increase this efficiency to approximately 90%. It is concluded that the algorithm is correct and can be made very efficient. Future work will focus on improving overall performance and continued validation.

This work was funded by the Consortium for Advanced Simulation of Light Water Reactors (CASL), an Energy Innovation Hub for Modeling and Simulation of Nuclear Reactors under the U.S. Department of Energy Contract.
Assessment of current boiling and Eulerian-Eulerian multiphase flow modeling capabilities in STAR-CCM+
Adam Kraus\textsuperscript{1}, Adrian Tentner\textsuperscript{2}

\textsuperscript{1}Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Nuclear Engineering Division, Argonne National Laboratory, Lemont, IL

Multiphase Computational Fluid Dynamics (CFD) is becoming an increasingly useful simulation tool, but boiling flows still present computational challenges. This work assesses capabilities of current sub-cooled flow boiling models within the Eulerian-Eulerian framework in the CFD code STAR-CCM+. This framework solves separate mass, momentum, and energy equations for each phase, with phase interaction terms as closures. Current STAR-CCM+ interactions are drag, lift, turbulent dispersion, virtual mass, and bulk and wall boiling/condensation. Three benchmark cases from the pressurized water reactor safety bundle tests were simulated, which feature a heated PWR center sub-channel geometry with operating reactor flow conditions (initially sub-cooled water at high pressure/temperature). The tests measured average volumetric void fraction in a small axial section. The simulated and measured void fractions for the 3 cases were 0.105 and 0.038, 0.285 and 0.311, 0.347 and 0.44, respectively. From these results, STAR-CCM+ tends to over predict low void cases and under predict high void cases, but provides acceptable results in the medium-range. Meshing studies and model substitutions confirmed these simulated results. Lift was challenging to implement and led to the most instability. No extended boiling framework currently exists in STAR-CCM+, so inability to adequately handle bubbly-to-slug transition may contribute to error in high void cases. Conjugate Heat Transfer (CHT) modeling might also help with the low void case especially. Future work utilizing CHT, particle size distribution, wall lubrication, and extended boiling framework should improve simulation accuracy.

\textit{This work was funded, in part, by the DOE Nuclear Energy Advanced Modeling and Simulation (NEAMS) Program.}
Active-interrogation measurements of induced-fission neutrons from low-enriched uranium

M. J. Marcath¹, J. L. Dolan¹, M. Flaska¹, S. A. Pozzi¹, D. L. Chichester², A. Tomanin³, P. Peerani³, D. Cester⁴, and G. Nebbia⁴

¹ Department of Nuclear Engineering and Radiological Sciences, University of Michigan
² Idaho National Laboratory, Idaho Falls, ID
³ European Commission, Joint Research Centre, Ispra, Italy
⁴ The National Institute of Nuclear Physics, Padova University, Padova 35131, Italy

Fast and robust controlling mechanisms to protect and control nuclear fuels are paramount for nuclear security and safeguards. Through both passive- and active-interrogation methods we can use fast-neutron detection to perform real-time measurements of fission neutrons for process monitoring. Active interrogation allows us to use different ranges of incident neutron energy to probe for different isotopes of uranium. With fast-neutron detectors, such as organic liquid scintillation detectors, we can detect the induced-fission neutrons and photons and work towards quantifying a sample’s mass and enrichment. Using MCNPX-PoliMi, a system was designed to measure induced-fission neutrons from U-235 and U-238. Measurements were then performed in the summer of 2011 at the Joint Research Centre in Ispra, Italy. Fissions were induced with an associated particle D-T generator and an isotopic Am-Li source. The fission neutrons, as well as neutrons from (n, 2n) and (n, 3n) reactions, were measured with five 5” by 5” EJ-309 organic liquid scintillators. The D-T neutron generator was available as part of a measurement campaign in place by Padova University. The measurement and data-acquisition systems were developed at the University of Michigan utilizing a CAEN V1720 digitizer and pulse-shape discrimination algorithms to differentiate neutron and photon detections. Low-enriched uranium samples of varying mass and enrichment were interrogated. Acquired time-of-flight curves and cross-correlation curves were analyzed to draw relationships between detected neutrons and sample mass and enrichment. MCNPX-PoliMi simulation results were compared to the measured data to validate the MCNPX-PoliMi code when used for active-interrogation simulations.

This work was funded, in part, by the U.S. Department of Energy Office of Nuclear Energy and the Material Protection Accountability and Control Technologies Program. Idaho National Laboratory is operated for the U.S. Department of Energy by Battelle Energy Alliance under DOE contract DE-AC07-05-ID14517.
MCNPX simulations of UF$_6$ neutron coincidence measurements using liquid scintillator detectors for $^{235}$U enrichment determination

Marc Paff$^1$, Shaun Clarke$^1$, Eric Miller$^1$, Sara Pozzi$^1$, Enrico Padovani$^2$

$^1$Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI
$^2$Politecnico di Milano, Dipartimento di Energia, via Ponzio 34/3, 20133 Milano, Italy

When safeguarding UF$_6$ cylinders, the determination of $^{235}$U enrichment and $^{235}$U mass of the solidified UF$_6$ is paramount. Current enrichment meter technology relates ratios of characteristic gamma-ray peak areas to the level of $^{235}$U enrichment. However, due to strong self-shielding effects, such instruments can only assess the outer-most UF$_6$ layers. Thus, little information can be gained on the composition of the inner UF$_6$ layers or on the bulk $^{235}$U mass. Concerns exist that more highly enriched UF$_6$ could be concealed inside a shell of low enriched UF$_6$. The spontaneous fission of $^{238}$U and especially the (alpha, neutron) reaction of $^{234}$U alpha particles on $^{19}$F provide significant neutron emission spectra. Neutrons, compared to gamma rays, are significantly less affected by self-shielding in UF$_6$. Consequently, there has been increased interest in developing neutron-based enrichment measurement devices. Organic liquid scintillators possess properties favorable towards fast timing and large detector volume applications. Fast timing arises from the liquid's very short, ns-scale fluorescence decay time. Using low cost liquids also grants flexibility in designing the detector's shape and volume. Also, pulse shape discrimination of gamma rays and neutrons is possible. The feasibility of using liquid scintillator detectors is being investigated using MCNPX-PoliMi simulations. Specifically, the possibilities of coupling measured neutron coincidences to algorithms to estimate the UF$_6$'s $^{235}$U enrichment are being explored. This poster includes results from extensive simulation studies on neutron coincidences, which are found to correlate with uranium enrichment and appear to provide counting rates allowing cylinder assays to be performed in minutes.

*This work was funded, in part, by the National Nuclear Security Administration’s Nuclear Nonproliferation International Safeguards Fellowship.*
An approach to isotopic analysis of actinides using active neutron interrogation
Bruce Pierson¹ and Michael Hartman

¹Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

The threat of illicit special nuclear material (SNM) trafficking is a serious concern for the international community. To address this situation, research groups across the country are working to develop, test, and implement remote sensing SNM detection methods. One method currently under investigation at the University of Michigan Neutron Science Laboratory (NSL), aims to use time dependent ratios of the intensities of the detected fission fragments to determine the isotopic content of actinide mixtures. The cumulative and individual fission yields for short-lived fission fragments far from the line of stability vary widely between different actinides. These differences are largest immediately after irradiation resulting in detectably significant variations in their delayed gamma-ray responses. Experiments performed at the NSL have characterized the response signature of thorium-232 using the facility’s pneumatic transfer system and accelerator-driven neutron generator. The collected data were compared to the predicted behavior derived from the predicted fission yields provided in evaluated nuclear data file ENDF-349 and the Bateman equations. Many of the measured ratios show excellent agreement with the modeled behavior. The maximum deviation between the fitted and predicted model for the zirconium-99 to lanthanum-146 intensity ratio was 10% and both models fell within two sigma of the data points. However, some show significant deviation from the model. These variations may be artifacts of poorly known fission yields or half-lives. The results of this experiment illustrate the power associated with the current method and may be a different approach to improving fundamental nuclear data.

This work was funded in part by the Nuclear Energy University Program (NEUP) Fellowship and the South Carolina University Research Education Foundation (SCUREF).
A method for in-situ studies of irradiation accelerated corrosion

Stephen S. Raiman¹, Alexander Flick¹, Ovidiu Toader¹, Fabian U. Naab¹, Nassim A. Samad¹, Zhijie Jiao¹, Gary S. Was¹

¹Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

The aggressive conditions inside light water reactors pose a risk to pressure vessel core internals. The conditions for aqueous corrosion are generally favorable due to the high temperature and concentration of oxidizing species. The addition of radiation has been shown to greatly accelerate corrosion. This experiment attempts to determine the mechanism by which irradiation accelerates corrosion. The effects of water radiolysis, displacement damage, and surface excitation production are studied to determine the relative contribution of each. Initial experiments were conducted in pure water at 130°C and 500 psi, with observed changes in dissolved oxygen level and conductivity of the irradiated water, suggesting radiolysis and oxidation. When plotted as a function of beam current density, a linear dependence can be seen. Examining the stainless steel sample after the irradiation, a distinct brown film is visible on the side interfacing with the water. The experiment was conducted at low temperature, so the nature of the film is difficult to characterize, although preliminary measurements have shown a small increase in surface oxygen concentration.

This work was supported by a grants from the DOE-NEUP, grant number DE-AC07-05ID14517 and EDF Contract No. 8610-BVW-4300243004.
Coupling fuel performance and neutron transport simulations
Michael Rose¹, Frederick Gleicher²

¹Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI
²Idaho National Laboratory, Idaho Falls, ID

Nuclear fuel performance in light water reactors is strongly dependent on the power density distribution in the fuel pins. BISON, a fuel performance code developed at Idaho National Laboratory, currently employs simplified models of the power density distribution based on the one energy group neutron diffusion approximation. This simple model may be improved by using neutron transport to obtain the accurate sub-pin level power density distribution. DeCART, a 3D, full-core neutron transport code developed at the University of Michigan and the Korean Atomic Energy Research Institute, has been coupled to BISON. DeCART has been used to provide power density, fission rate density, and fast neutron flux data to BISON (fast neutron flux data is important in predicting the behavior of the fuel cladding over the fuel lifetime.) Two-way coupling has been established: BISON sends a fuel temperature distribution to DeCART in order to update the neutron cross-section data. Multiple single-pin simulations have been performed for one year of normal operation. Preliminary results have shown that it is important to have a fine radial mesh in the fuel pin due to the strongly varying power density brought about by plutonium build up on the rim of the fuel pin. Preliminary results suggest that the neutron transport equation eigenvalue converges quickly with two-way data transfer.

This work was funded, in part, by the Department of Energy Nuclear Energy University Programs (NEUP) and Idaho National Laboratory
Analysis of the antineutrino signature of LEU/MOX fueled LWRs

Thomas G. Saller¹, Andrew M. Ward¹, Tom Downar¹.

¹Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

One way to reduce the amount of weapons-grade plutonium is to convert it to mixed-oxide (MOX) fuel and then burn it in existing reactors. This process will require oversight and verification. Anna Hayes (LANL) at the 2006 Applied Antineutrino Physics Workshop demonstrated one potential verification method. Differences in antineutrino production over a burn-up cycle are used to differentiate between a low-enriched uranium (LEU) light water reactor (LWR) and a MOX LWR. This difference occurs because of the differences in evolving fissile isotopics between MOX and LEU assemblies. This work involves a more detailed analysis of antineutrino production for LWRs. Different enrichment LEU and MOX assemblies are depleted to obtain time-dependent antineutrino production rates. These assemblies are then simulated at several burn-up steps and combined to obtain the antineutrino rate at the start of a fuel cycle in an equilibrium partially-MOX core. Parametric studies are performed with the equilibrium core to determine if diversion of weapons-grade MOX fuel assemblies is detectable using the antineutrino response. Results indicate that while the evolution of antineutrino production during a single burn-up cycle does vary with enrichment, those differences are minor compared to the differences between LEU and MOX fuel. Furthermore, the ability to detect the removal of weapons-grade MOX assemblies from a core depends on whether it is replaced with LEU (more detectable) or reactor-grade MOX (less detectable).

This work was funded, in part, by DOE NNSA Stewardship Science Graduate Fellowship.
Short-pulse, high-energy radiation generation using a laser wakefield accelerator

Will Schumaker¹, G. Sarri², M. Vargas¹, V. Chvykov³, B. Dromey², B. Hou³, A. Maksimchuk³, J. Nees³, V. Yanovsky³, M. Zepf², A.G.R. Thomas¹, and K. Krushelnick¹.

¹Department of Nuclear Engineering, University of Michigan, Ann Arbor, MI
²Department of Physics, Queen's University, Belfast, UK
³Center for Ultrafast Optical Science, University of Michigan, Ann Arbor, MI

Recent experimental results of laser wakefield acceleration (LWFA) of electrons and their subsequent radiation generation driven by the HERCULES laser with up to 200TW are presented. In LWFA, the laser-driven plasma “bubble” structure forces trapped, off-axis electrons to undergo transverse oscillatory motion during acceleration, resulting in synchrotron-like betatron radiation in the keV X-ray regime. Measurements indicate that the beam source size can be as small as 1 micron and that the radiation exhibits spatial coherence, allowing phase-contrast imaging. Data from Cu K-α generated using an identical geometry are presented to give yield and source size comparisons. Alternatively, the high-energy (>200 MeV) electron beam can be subsequently converted via Bremsstrahlung into low-divergence beams of high-energy photons and positrons. These photons are spectrally resolved using a Compton scattering-based, high-energy (30-80 MeV) photon spectrometer. All of these subsequent beams are presumed to retain the short-pulse characteristic of the electron beam, resulting in high peak flux, making the source an excellent candidate for ultrafast pump-probe applications in the keV and MeV photon range.

This work was funded, in part, by DOE & NSF-PHY Grant # 0810979.
Non-destructive uranium enrichment measurements using fast neutron spectroscopy

Michael Streicher¹, Scott Kiff², Mark Gerling², Peter Marleau², and Wondwosen Mengesha²,

¹Department of Nuclear Engineering & Radiological Sciences, University of Michigan, Ann Arbor, MI
²Radiation and Nuclear Detection Systems, Sandia National Laboratories*, Livermore, CA

A major challenge in international nuclear safeguards exists at enrichment facilities where non-destructive measurements of the isotopic composition of uranium-235 are still being improved. This research evaluates the feasibility of using fast neutron imaging and spectroscopy to perform a holistic assay of a storage cylinder. Liquid scintillator radiation detectors and storage containers housing uranium hexafluoride were simulated in MCNP-PoliMi. Fast neutrons were generated and transported through the geometry to determine the flux at the face of the liquid scintillators. A post-processing code was used to simulate detector response. In uranium hexafluoride, fast neutrons are generated via spontaneous fission in $^{238}$U, induced fission in $^{235}$U, and $(\alpha, n)$ reactions where $\alpha$ particles are emitted from $^{234}$U and incident on fluorine atoms. The fission spectra differ significantly from the $(\alpha, n)$ spectrum. Furthermore, the $^{234}$U concentration is proportional to the $^{235}$U concentration, so it was expected that the $(\alpha, n)$ spectrum would become more pronounced with increased enrichment. However, results indicated that higher enrichment yields more induced fissions than expected, making it difficult to observe the features from the $(\alpha, n)$ spectrum, and thus, difficult to resolve the enrichment level from fast neutron spectroscopy. Future efforts will be applied to neutron multiplicity counting.

This work was funded, in part, by Sandia National Laboratories Lab Directed Research and Development Program
Simulation of plasma dynamics of electrical discharges sustained in bubbles in water images and optical spectra
Wei Tian\textsuperscript{1}, Mark J. Kushner\textsuperscript{2}

\textsuperscript{1}Department of Nuclear Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Dept. of Electrical Engr. & Computer Science, University of Michigan, Ann Arbor, MI 48109, USA

Electrical discharges in bubbles in water are of great interest to applications ranging from environmental cleanup to chemical processing due to their ability to produce chemically reactive species such as hydrogen peroxide, hydroxyl and oxygen radicals. In this paper, we report on a computational investigation of the plasma dynamics of electrical discharges in bubbles in water with the goal of quantifying the basic processes and potential applications of these systems. These simulations were performed using nonPDPSIM, which solves Poisson's equation and transport equations for charged species and electron temperature. Water vapor is allowed to diffuse into the bubble from the water-boundary where its density is given by the saturated water vapor. Computed synthesized images and optical spectra from the bubbles are compared to recent experiments by Tachibana et al. Our results show that the electron temperature and the energy relaxation length are the dominating factors for the discharge behaviors and the excitation transfer processes from discharge gases to water vapor are responsible for the optical spectra.
High fidelity simulation of crud deposition on a PWR fuel cell

Daniel Walter ¹, Ben Collins ¹, Victor Petrov ¹, Brian Kendrick ², Annalisa Manera ¹

¹Nuclear Engineering and Radiological Sciences Department, University of Michigan, Ann Arbor, MI
²Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM

Heavy crud deposits on fuel rods in commercial nuclear reactors have led to axial offsets of the power distribution, known as crud-induced power shifts (CIPS), causing the utility to reduce core power in order to maintain power peaking limits. The build-up of crud also contributes to thinning of the fuel clad wall, resulting in crud-induced localized corrosion (CILC) failures. There are two main feedback mechanisms involved in crud deposition. The occurrence of hot spots on the cladding surface leads to an increase of the local crud deposition, while the presence of boron-10 (a strong neutron absorber) in the crud reduces the local power. To capture these feedbacks, a high fidelity, three-way coupled simulation is necessary. DeCART (neutron transport) provides the power density to STAR-CCM+ (computation fluid dynamics), returning the material temperatures and coolant density. STAR-CCM+ provides the heat flux, cladding temperature, and turbulent kinetic energy to MAMBA (crud chemistry), returning the crud thermal resistance. MAMBA provides DeCART the crud thickness and composition, returning the coolant boron concentration and the boron reaction rate. The results of this 500 day depletion simulation have reproduced the typical “striping” pattern observed in crud deposits downstream of the spacer grids. This phenomenon occurs due to the feedback between hot spots on the cladding surface and crud deposition, as well as the existence of crud erosion from local shear stresses. Additionally, the uptake of boron-10 into the crud layer has also been modeled, which demonstrates the direct effect on the axial power distribution within the core.

This work was funded, in part, by the Consortium for Advanced Simulation of Light Water Reactors (CASL).
Power and Control

Session Chairs: Yu-Ju Lin and Adam Mendrela
A distributed wireless testbed for plug-in hybrid electric vehicle control algorithms

Ian Beil¹, Ian Hiskens¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Abstract—There is a desire within the scientific community to use the inherent storage capabilities of plug-in hybrid electric vehicle batteries to enable demand-side management in power systems, increasing the usability of variable generation such as wind and solar power. The potential advantages of increased grid control must be tempered against the harmful effects of charge/discharge cycles on car battery health as well as user constraints on maximum allowable charge time. This paper reviews past research on communication and control architectures for PHEV charging and proposes a novel testbed to allow physical testing of several of the proposed schemes.

This work was funded, in part, by the Department of Energy under Award Number DE-PI0000012, through the Clean Energy Research Center - Clean Vehicle Consortium.
Supervisory control for collision avoidance in vehicular networks using discrete event abstractions
Eric Dallal\(^1\), Alessandro Colombo\(^2\), Domitilla Del Vecchio\(^3\), Stéphane Lafortune\(^1\)

\(^1\)Department of Electrical Engineering, University of Michigan, Ann Arbor, MI  
\(^2\)Department of Mechanical Engineering, Politecnico di Milano, Italy  
\(^3\)Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA

We consider the problem of collision avoidance at vehicular intersections for a set of controlled and uncontrolled vehicles that are linked by wireless communication. We consider three system requirements: (R1) safety, i.e., vehicular collisions must be avoided; (R2) non-blockingness, i.e., vehicles must completely cross the intersection; and (R3) maximal permissiveness, i.e., the solution should leave as much autonomy as possible to the individual vehicles. Therefore, rather than computing a single, specific solution to any problem instance, we compute a supervisor which allows all behavior satisfying requirements (R1) and (R2). The vehicles are modeled by a first order system with bounded model uncertainty. We begin with a continuous time and continuous space model and formal definitions of requirements (R1), (R2), and (R3) on the system behavior. We proceed by discretizing the system in space and time, resulting in a discrete event system over which we translate all the system requirements of the continuous time system. The solution at the discrete event level is then obtained by computing the supremal controllable sublanguage in the non-blocking case, a standard problem in discrete event systems. In this work, we develop algorithms which allow us to take advantage of geometric properties of the problem and structural properties of the abstraction in order to compute a solution more efficiently. The final step in our solution is to translate the discrete event level supervisor back to continuous time. In order to more effectively demonstrate our solution, we have implemented our algorithms in a visual simulation tool.

*This work was funded, in part, by NSF grant CNS-0930081.*
Hysteresis-based charging control of plug-in electric vehicles
Soumya Kundu¹, Ian Hiskens¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Reports estimate that by 2020, plug-in electric vehicles (PEVs) might contribute up to 6% of total electricity demand in USA. Unregulated charging of a large fleet of PEVs, mostly concentrated overnight (when the non-PEV demand is lowest and wind generation highest), will pose operational difficulties for the ageing and near-saturated grid infrastructure. The work presented here develops a hysteresis-based charging control strategy for PEVs that is capable of regulating charging load to satisfy system-wide services, including filling the overnight demand `valley" and balancing fluctuations in renewable generation. The actual state-of-charge (SoC) of a PEV battery follows a nominal SoC profile within a small hysteresis band. This leads to a sequence of ON and OFF cycles for the charger. The work shows that in steady-state the probability distributions of SoC in the ON and OFF states, normalized around the nominal profile, follow a uniform distribution over the hysteresis deadband. Based on this steady-state behavior, a linearized state-space model has been developed to capture the response of aggregate electricity demand to shifts in the nominal SoC profile. A feedback control law is designed based on this linearized model.

This work was funded, in part, by the National Science Foundation through EFRI-RESIN grant 0835995, and the Department of Energy through the Clean Energy Research Centre for Clean Vehicle Collaboration (CERC-CVC), award number DE-PI0000012.
13.56 MHz high density dc-dc converter with PCB inductors
Wei Liang\textsuperscript{1}, John Glaser\textsuperscript{2}, Juan Rivas\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}General Electric Global Research, Niskayuna, NY

This poster presents the design and implementation of a high density 170 V to 28 V, 400 W resonant dc-dc converter with embedded inductors. The converter has a switching frequency of 13.56 MHz and uses air--core toroidal inductors fabricated with printed circuit board (PCB) technology. Implementing the inductors with the PCB minimizes unwanted stray magnetic fields and parasitics, and reduces undesired coupling to the rest of the circuit. By not using magnetic cores, the inductors maintain stable values over a wide temperature range. The poster discusses a semi-automated tuning algorithm to simplify the circuit design. This eases the difficulties in the tuning procedure compared to many resonant topologies. Moreover, the poster discusses the trade-offs between simplicity and performance of implementing a hard-switched gate drive at MHz switching frequencies and provides guidelines on layout and thermal considerations. We describe the advantages of resonant power converter topologies in applications requiring high density and high performance in demanding environmental conditions.

This work is funded by the Automotive Research Center and U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) under Cooperative Agreement W56HZV-04-2-0001.
Impact of wind power variability on sub-transmission networks

Sina Sadeghi Baghsorkhi and Ian Hiskens

1Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The integration of inherently variable wind generation into weak grids, particularly sub-transmission networks that are characterized by low $\lambda/R$ ratios, significantly affects bus voltages, regulating devices and line flows. This work examines the impact of wind generation on sub-transmission networks, focusing particularly on the effect of power flow variability on the voltage profile and tap-changing operation of OLTC transformers, the key voltage regulators of sub-transmission and distribution networks. Although voltage regulation at the point of wind interconnection is indispensable, the analysis presented in our work suggests that it has a detrimental effect on tap-changer operation for the transformers that connect the sub-transmission network (40 kV) to the transmission system (120 kV). Wind farm voltage regulation tends to increase the sensitivity of tap position to wind power variations, and significantly increases the number of tap change operations. Consequently, the life of these expensive assets will be decreased, hindering the development of wind power in weak grids. On the other hand, lack of voltage regulation at wind farms leads to unacceptable voltage fluctuations within the sub-transmission network. The trade-off between local voltage regulation and tap change frequency is fundamentally important in optimizing the size of reactive compensation used for voltage regulation at wind injection nodes.
Computationally-efficient finite-element-based 3d thermal models of electric machines
Kan Zhou¹, Jason Pries¹, Heath Hofmann¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Knowledge of the internal temperatures of an electric machine under real-time operating conditions would be extremely useful in order to determine its torque capabilities. This knowledge is also useful for full-scale electric vehicle simulation and optimization.

In this poster, we present a technique for developing computationally-efficient thermal models for electric machines that can be used for real-time thermal observers and vehicle-level simulation and optimization. The technique is based upon simulating the eigenmodes of the thermal dynamics as determined by 3D finite element analysis. The order of the model is then dramatically reduced in two ways. First, the dynamic system is decomposed into two parts by using the orthogonal property of the eigenvectors. The extent of excitation of each eigenmode is calculated, and only eigenmodes that are significantly excited are included in the dynamic model; other eigenmodes are treated as static modes. Second, only a few "hot spots" in various regions are chosen.

The result is a thermal model that can accurately model internal temperatures of the machine while requiring the modeling of only a handful of states. Such a model can be used in vehicle simulations, or for real-time observers in actual vehicles. To verify the proposed model, a test-bed has been built and thermal experiments have been undertaken. Step command and a real driving cycle command have been used to run the thermal experiments. Both simulation and experimental results are shown in this seminar. The computation time of the model presented is dramatically reduced compared with a typical full-order finite element model while maintaining satisfying accuracy.

This work is funded by the Automotive Research Center (ARC), a U.S. Army Center of Excellence for Modeling and Simulation of Ground Vehicles led by the University of Michigan.
RF and Applied Electromagnetics

Session Chair: Gurkan Gok
Elimination of beam squint in serially fed arrays using negative group delay circuits
Waleed Alomar$^1$ and Amir Mortazawi$^1$

$^1$Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

A novel design technique for a serially fed antenna array employing the use of a negative group delay (NGD) circuit is reported in this paper. The NGD is generated using an antenna and a T-junction power divider. To the best of the authors’ knowledge, this is the first demonstration of employing an antenna for generating NGD. The required group delay and positive group delay, which is caused by interconnecting elements between the adjacent antennas, cancel the effect of each other. This results in a constant phase shift and a beam squint elimination over the entire antenna bandwidth. A phase variation within ±1 degree in a bandwidth of 160 MHz at a center frequency of 10.1 GHz has been measured in this design.
A mm-scale autonomous heterogeneous wireless sensor node

Elnaz Ansari¹, Yoonmyung Lee¹, Kuo-Ken Huang¹, Inhee Lee¹, Jonathan K. Brown¹, Suyoung Bang¹, Hyeongseok Kim¹, Yejoong Kim¹, Ryan R. Rogel¹, Gyouho Kim¹, Seok Hyeon Jeong¹, Sechang Oh¹, Pat Pannuto¹, Prabal Dutta¹, Dennis Sylvester¹, David Blaauw¹, David Wentzloff¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Ubiquitous sensing is projected to reach volumes of 1000 sensors per person by 2017, a number that will dwarf the current cell-phone market. With low-power computing as the initial spark, sensor-nodes have reduced in volume by 100X over the past decade, with cubic-mm sensors now a reality. The primary challenge of mm-scale sensors is power management due to severely limited harvested and stored energy. Furthermore, mm-scale battery technology requires efficient, integrated power conversion, meticulous duty-cycling of high-power modules, ultra-low leakage power, and under-voltage/over-current battery-protection circuitry. This work presents a fully-integrated, heterogeneous die-stacking, 6mm×3mm×3mm autonomous wireless sensor node, capable of integrating with various sensors using custom, low-power I2C hardware. It contains a crystal-less IR-UWB radio, on-board antenna, Li-ion micro-battery, digital system controller, inductor-less power management unit, and decoupling capacitor to supply large peak currents to the radio. The standalone node demonstrates node-to-base-station communication up to 2.5m. The system operates from an integrated 3.6V, rechargeable micro-battery, and is designed to consume less than 72µW on average when active, and minimize power consumption when asleep. The power management unit generates 1.2V and 0.6V supplies to reduce power consumed by the digital control, and includes current-limiting circuitry to protect the battery while the high-power blocks are active. The system can be initially programmed via an optical interface or I2C interface, after which it is completely autonomous.

This work was funded, in part, by the National Science Foundation under Grant Number CNS-1111541.
Experimental verification of tensor transmission-line metamaterials: a printed beam-shifting slab

Gurkan Gok¹ and Anthony Grbic¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Transmission-line based metamaterials possessing effective material parameter tensors have been introduced by the authors in 2010. These tensor transmission-line (TL) metamaterials provide a link between microwave network theory and transformation optics. As such, they have also been referred to as transformation circuits. To date, these metamaterials have been modeled analytically, and their propagation characteristics have been verified through full wave simulation. Moreover, homogenization techniques to accurately calculate their tensor material parameters have been recently proposed by the authors. In this presentation, the electromagnetic properties of tensor TL metamaterials are experimentally verified. Specifically, the design and implementation of a beam-shifting slab using tensor transmission-line metamaterials is reported. A beam-shifting slab is a transformation optical device which laterally displaces the electromagnetic field transmitted through it. The slab is magnetically anisotropic with a full 2X2 permeability tensor. Nonetheless it is impedance matched to the surrounding isotropic medium for all angles of incidence. The anisotropic slab and medium surrounding it are implemented using printed metamaterial unit cells. A cylindrical source is used to excite the overall structure. The properties of the tensor transmission-line metamaterials employed in the design will be described in the presentation. In addition, the homogenization technique used to accurately predict the effective material parameters of the metamaterial unit cells comprising the slab and surrounding medium will be reviewed. Finally, simulation and measurement results of the beam-shifting slab will be detailed and compared.

This work was funded, in part, by Presidential Early Career Award for Scientists and Engineers (FA9550-09-1-0696)
Analysis of printed-circuit tensor impedance surfaces
Amit M. Patel\textsuperscript{1} and Anthony Grbic\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The propagation characteristics of electromagnetic waves on various isotropic (scalar) impedance surfaces have been studied for some time, in order to control surface waves and leaky-wave radiation. One and two dimensional periodic impedance surfaces as well as tensor impedance surfaces, have been explored for enhanced control of wave guidance. The desire to integrate antennas and other electromagnetic devices onto the surfaces of vehicles and other platforms has driven this interest in both scalar and tensor impedance surfaces. Tensor impedance surfaces have been implemented as two-layer structures, consisting of planar metallic patterns printed over a grounded dielectric substrate. To date, it has been assumed that these two-layer structures can be approximated as single surfaces. Using this approximation can simplify the design process but may inadequately model propagation and guidance characteristics. A more accurate method for analyzing and designing tensor impedance surfaces is described in this presentation. The tensor impedance surface is modeled as a two-layer structure consisting of a tensor sheet impedance over a grounded dielectric substrate. In this work, a method for analytically predicting the full modal behavior of a two-layer tensor impedance is presented. First, the dispersion equation of an arbitrary tensor sheet impedance over a grounded dielectric substrate is derived using a modified transverse resonance technique. Next, a two-dimensional sheet impedance extraction method is presented. By combining the dispersion equation for the two-layer structure and the sheet impedance extraction method, the full modal behavior of an example geometry is predicted analytically and verified through full-wave eigen-mode simulations.

\textit{This work was partially supported by a Presidential Early Career Award for Scientists and Engineers (FA9550-09-1-0696), a NSF Faculty Early Career Development Award (ECCS-0747623), and by the Science, Mathematics and Research for Transformation (S.M.A.R.T) Fellowship sponsored by the U.S. Department of Defense (DoD) and the American Society for Engineering Education (ASEE).}
Controlling ion and UV/VUV photon fluxes in pulsed low pressure inductively coupled plasmas for materials processing

Peng Tian\(^1\) and Mark J. Kushner\(^1\)

\(^1\)Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Low pressure plasmas are widely used to modify the surface properties of materials. This is accomplished through a sequence of surface reactions which is initiated by fluxes of reactive species, including electrons, ions, excited neutrals and photons. In particular, UV and VUV photons are increasingly being recognized important in surface processes. Synergistic interactions between ion and UV/VUV photon fluxes have been found that may produce undesirable reactions at and below the material surface. This has motivated us to develop methods to separately control ion and UV/VUV photon fluxes, or at least to control their relative fluxes. Pulsed plasmas are promising for this purpose because ion and photon fluxes respond to pulsed power deposition at different rates. In this project, pulsed inductively coupled plasmas (ICPs) were computationally investigated as a mean to control relative fluxes (or flux ratios) of ions and photons to substrates in material processing reactors. The pulsed ICPs are generated by application of square-wave modulated radio frequency (RF) power to a planar antenna. The computational platform is a 2-dimensional hydrodynamics model with radiation transport addressed by a spectrally resolved Monte Carlo simulation. We investigated plasmas in Ar/Cl\(_2\) gas mixtures at low pressure (10's of mTorr) using a 20 μs pulse period. It was found that with fixed average power, the time averaged ratio of photon-to-ion fluxes in ICPs can be controlled by varying the duty cycle of the pulsed plasma, aspect ratio of the reactor and gas pressure.

*This work was funded by Department of Energy Office of Fusion Energy Science, and the Semiconductor Research Corp.*
Design and evaluation of a class of miniaturized on-metal antenna
Jiangfeng Wu\textsuperscript{1} and Kamal Sarabandi\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Reactive impedance surface (RIS), known as meta-substrate, have shown the ability to miniaturize printed antennas with omni-directional radiation pattern, when served as the substrate for the antenna. However, the area of conventional RIS substrate usually has to much larger than that of miniaturized antenna, since the cell's dimension is comparable with the antenna, even using a high dielectric constant of 10.2 or 25. This paper presents a two-layer mushroom-like RIS and its application to patch antenna miniaturization. The proposed compact two-layer RIS can achieve 76\% lower resonance frequency than conventional one-layer RIS with the same size, whose cell dimensions are limited within $\lambda_0/45$ in length and $\lambda_0/100$ in height while the dielectric constant is kept below 3.5. This makes it possible to design a miniaturized antenna over an RIS substrate with the same size as the antenna itself. The RIS substrate is analyzed by a surface impedance model. A microstrip transmission line over the RIS substrate is studied and shown to have a high propagation constant near the resonance frequencies of the RIS. A model based on simulation results of wide microstrip line over RIS is used to predict the much reduced resonant frequency of patch antennas over the RIS. Applying the two-layer RIS substrate and an optimized miniaturized patch antenna topology, several UHF band patch antenna working around 400MHz has been designed and fabricated. Using this approach a miniaturized antenna with dimensions $\lambda_0/11.4 \times \lambda_0/11.4 \times \lambda_0/74$, including the RIS substrate is developed.
Signal Processing and Computer Vision

Session Chair: Michgael Allison
Frequency-difference beamforming with sparse arrays
Shima H. Abadi¹, Heechun Song², David R. Dowling¹

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
²Marine Physical Laboratory, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA

When an acoustic signal is transmitted to a remote receiving array with sufficient aperture and transducer density, the arrival direction(s) of the ray paths linking the source and the array may be determined by beamforming the transducer recordings. However, when the receiving array is sparse, i.e. there are many signal wavelengths between transducers; the utility of conventional beamforming is degraded because of spatial aliasing. Yet, when the signal has sufficient bandwidth, such aliasing may be mitigated or eliminated through use of an unconventional nonlinear beamforming technique that manufactures a desired frequency difference from the recorded signals. When averaged through the signal's frequency band, the output of frequency-difference beamforming is similar to that of conventional beamforming evaluated at the desired difference frequency. Results and comparisons from simple propagation simulations and FAF06 experimental measurements are shown for broadband signal pulses (11-19 kHz) that propagate 2.2 km underwater to a vertical 16-element receiving array having a 3.75-m-spacing between elements (almost 40 signal-center-frequency wavelengths). Here, conventional delay-and-sum beamforming results in the signal's frequency band are featureless, but received ray-path directions are successfully determined using frequency differences that are well below the broadcast signal's frequency band.

This work was funded, in part, by ONR.
Alternating direction method of multipliers algorithms for MR coil sensitivity estimation
Michael J. Allison¹, Sathish Ramani¹, Jeffrey A. Fessler¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Several magnetic resonance (MR) parallel imaging techniques require explicit estimates of the receive coil sensitivity profiles. These estimates must be accurate over both the object and its surrounding regions to avoid generating artifacts in the reconstructed images. Regularized estimation methods that involve minimizing a cost function containing both a data-fit term and a regularization term provide robust sensitivity estimates in these regions. However, these methods can be computationally expensive when dealing with large problems. We propose an augmented Lagrangian based method that estimates the coil sensitivity profile by minimizing a quadratic cost function. Our method reformulates the finite differencing matrix in the regularization term to enable exact alternating minimization steps. We also present a faster variant of this algorithm using intermediate updating of the associated Lagrange multipliers. Numerical experiments with simulated and real data sets indicate that our proposed method converges approximately twice as fast as the preconditioned conjugate gradient method (PCG). These principles can be generalized to other regularized image estimation problems.

This work was funded, in part, by NSERC and NIH-CA87634.
The performance of deterministic matched subspace detectors: informative versus useful subspace components
Nicholas Asendorf\textsuperscript{1}, Prof. Raj Rao Nadakuditi\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Many signal processing and machine learning applications involve the abstract task of detecting a signal of interest buried in high dimensional noise. A matched subspace detector (MSD) is commonly used to solve this problem when the target signal is assumed to lie in a low-rank subspace. The standard deterministic MSD is an “energy detector” that sums the energy of an observation lying in the signal subspace. An oracle detector, which assumes knowledge of the signal subspace, gives an upper bound on detector performance. When the signal subspace is unknown, a subspace estimate can be formed from a finite set of training data collected under similar noisy conditions. This estimated subspace is then substituted for the unknown subspace in the oracle detector. While this plug-in detector is realizable, it suffers a performance loss relative to the oracle detector because the subspace estimate is inaccurate due to limited training data. By using random matrix theory results that precisely quantify the accuracy of this subspace estimate, we derive ROC performance curves for the deterministic plug-in detector. This analysis shows that not only are some subspace components uninformative, but that even informative subspace components may not be useful in detection. We demonstrate this phenomenon using numerical simulations and show that there is an optimal number of subspace components to use in a deterministic MSD.

This work was funded, in part, by the ONR Young Investigator Award N00014-11-1-0660 and ARO MURI W911NF-11-1-0391.
Semantic structure from motion
Yingze (Sid) Bao\textsuperscript{1}, Mohit Bagra\textsuperscript{1}, Yu-Wei Chao\textsuperscript{1}, Silvio Savarese\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor

We propose a new framework for jointly recognizing objects as well as reconstructing the underlying 3D geometry of the scene (cameras, points, regions, and objects). In our SSFM framework we leverage the intuition that measurements of keypoints, regions, and objects must be semantically and geometrically consistent across view points. Our SSFM framework has the unique ability to: i) estimate camera poses from object detections only; ii) enhance camera pose estimation, compared to feature-point-based SFM algorithms; iii) improve object detections and region recognition given multiple uncalibrated images, compared to independently detecting objects or recognizing regions in single images.

\textit{This work was funded, in part, by Giga Scale Research Center and NSF CAREER #1054127.}
Accelerating multi-frame image reconstruction with variable-splitting approach
Jang Hwan Cho¹, Sathish Ramani¹, Jeffrey A. Fessler¹.

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

There are a variety of imaging modalities that record a sequence of measurements where the sensor and/or the objects in the scene are moving and the goal is to reconstruct an image without motion blur. Examples include multi-frame super-resolution problems and motion-compensated image reconstruction problems in medical imaging. Various methods have been proposed for such applications, often in the context of specific imaging modalities. However, many such methods can be formulated in a common framework and thus solved by the same optimization method. To solve the reconstruction problem efficiently, the optimization method must be designed carefully. The formulation of the problem and the characteristics of the system model have critical roles in determining which optimization methods are efficient. This study proposes a novel approach to solve multi-frame image reconstruction problems more efficiently. We use a variable-splitting technique to dissociate the original problem into a few simpler problems that are then solved individually using an alternating minimization method. The proposed method is amenable to preconditioning, parallelization, and application of block iterative algorithms to the sub-problems. The proposed method is illustrated with a simulation of cardiac CT, which is very important for diagnosing heart disease. Simulation results demonstrate that even with simple diagonal or circulant preconditioners, the proposed method converges faster than the conjugate gradient (CG) method.

This work was funded by GE Healthcare.
Robust super resolution using a variable splitting method

Alan Chu¹, Mai Le², Matthew Muckley¹, Feng Zhao¹², Jeffrey Fessler²

¹Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
²Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The super resolution problem is an image reconstruction problem that produces a high resolution image from a set of low resolution images. Super resolution methods using L1 data fit terms and total variation regularizers have been shown to be more robust than methods using L2 data fit terms in the presence of non-Gaussian noise models, such as salt and pepper noise. However, few optimization algorithms are designed for L1 data fit terms. In addition, the super resolution problem can be complicated and computationally intensive due to the combined operations of downsampling, blurring, and motion. We present a novel application of the augmented Lagrangian method to the robust super resolution problem with a L1 data fit term and total variation regularization. We designed the augmented Lagrangian based algorithm to solve the original constrained problem by introducing an equivalent Lagrangian cost function with auxiliary variables, reducing the original problem to a set of simpler, entwined optimization problems. By exploiting the structure of system matrices to formulate exact update steps and by interleaving variable updates with Lagrange multiplier updates, we were able to optimize the algorithm's performance in a super resolution context. Our results show that splitting methods can solve L1 data fit term super resolution problems with comparable solution quality to existing methods.
A log-based closed-loop deep brain stimulation SoC
Jaehun Jeong¹, Hyo-Gyuem Rhew¹, Jeffrey Fredenburg¹, Sunjay Dodani², Parag Patil³, Michael P. Flynn¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
²Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
³Department of Neurosurgery, University of Michigan, Ann Arbor, MI

Deep brain stimulation (DBS) of the subthalamic nucleus is an effective therapy for numerous neurological disorders including Parkinson’s disease and tremor. There have been several SoCs incorporating neural recording and stimulation based on spike sorting algorithm, but the algorithm is not proven to be effective for closed-loop DBS. As the energy of local field potential (LFP) has recently emerged as a more effective feedback indicator for DBS, we present a log-based wirelessly-powered closed-loop DBS SoC that optimizes stimulation parameters by analyzing LFP energy rather than a spike sorting. The DBS system consists of LNAs, a log-ADC, digital log-filters, a log-DSP with a PI-controller, a current stimulator, an RF transceiver, a clock generator, and an RF-DC converter. In this system, neural signals are digitized by a log-ADC and directly processed in log-domain, resulting in reduced power consumption by replacing multiplication with addition, and squaring with 1-bit shifting respectively. The recorded neural data as well as LFPs and spikes can be transmitted to an external receiver by a backscatter RF transmitter. The system is powered from a 915MHz carrier by an RF-DC converter. The 4mm² chip in 180nm CMOS consumes 468μW for recording and processing neural signals, stimulation, and RF communication.
An iterative, backscatter-analysis based algorithm for increasing transmission through a highly-backscattering random medium
Curtis Jin¹, Raj Rao Nadakuditi¹, Eric Michielssen¹, Stephen Rand¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Materials such as turbid water, white paint and egg shells are opaque because it is impossible for light to pass straight through them. In such media, the randomly arranged particles cause light to scatter in random directions, thereby frustrating its passage. As the thickness of a slab of highly scattering random medium increases, this effect becomes more pronounced, and less and less light is transmitted through. We are interested in increasing the transmission of light through such scattering random medium and we consider “shaped wavefronts”, i.e. linear combination of planewaves of different angles. Then, it will be possible for the random medium to have a special wavefront called open eigenchannel, which yields 100% transmission. Open eigenchannels have been observed in our high-precision numerical simulation and using these channels has given us dramatic gain. We develop a physically-realizable algorithm for increasing transmission through random medium using backscatter analysis and the algorithm finds the open eigenchannel if the channel exists. The contribution of our algorithm is that it uses backscatter analysis to increase transmission; the wavefront being sensed is the backscattered wavefront as opposed to the transmitted wavefront in conventional approaches. We analyze the algorithm’s rate of convergence to the maximum transmitting wavefront and show via numerical simulations that it converges rapidly.

*This work was supported by NSF-CCF award.*
Relating things and stuff by high-order potential modeling
Byung-soo Kim\textsuperscript{1*}, Min Sun\textsuperscript{1*}, Pushmeet Kohli\textsuperscript{2}, Silvio Savarese\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Microsoft Research, Cambridge, UK
*Indicates equal contributions

In the last few years, substantially different approaches have been adopted for segmenting and detecting "things" (object categories that have a well-defined shape such as people and cars) and "stuff" (object categories which have an amorphous spatial extent such as grass and sky). This paper proposes a framework for scene understanding that relates both things and stuff by using a novel way of modeling high order potentials. This representation allows us to enforce labeling consistency between hypotheses of detected objects (things) and image segments (stuff) in a single graphical model. We show that an efficient graph-cut algorithm can be used to perform maximum a posteriori (MAP) inference in this model. We evaluate our method on the Stanford dataset by comparing it against state-of-the-art methods for object segmentation and detection.
Spatially adaptive majorization method for X-ray CT image reconstruction
Donghwan Kim¹, Jeffrey A. Fessler¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Statistical image reconstruction algorithms in X-ray CT provide improved image quality for reduced dose levels but require long compute time. Iterative algorithms that converge in fewer iterations and that are massively parallelizable are favorable in modern computing architecture. The separable quadratic surrogate (SQS) algorithm is desirable as it is simple and updates all voxels simultaneously, but it requires many iterations to converge. In this work, we propose an enhanced version of SQS algorithm that accelerates convergence using the proposed spatially adaptive majorization method. Previously, non-homogeneous iterative coordinate descent (NH-ICD) has accelerated the ICD algorithm by more frequently visiting the voxels that need more updates. This is reasonable because the difference between the initial and optimal images is non-uniform. Inspired by the NH idea, we have derived a new version of the SQS algorithm that leads to spatially non-uniform updates. The non-uniform (NU) SQS adaptively encourages larger step sizes for the voxels that are expected to change more between the current and the final image. We provide a theoretical justification for the acceleration of NU method. The proposed derivation of NU-SQS based on the De Pierros’s idea guarantees the monotonicity of minimization. We use CT scans to demonstrate that the proposed SQS algorithm converges faster than the ordinary algorithms by a factor of three.

This work was funded, in part, by NIH grant R01-HL-098686.
Parallel architecture for forward- and back-projection in X-ray computed tomography
Jung Kuk Kim¹, Jeffrey A. Fessler¹, Zhengya Zhang¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Iterative algorithms for 3D image reconstruction in X-ray computed tomography (CT) improve the image quality over conventional filtered back-projection. 3D forward- and back-projection in the iterative algorithm is one of the most computationally intensive operations, and necessarily requires multi-core microprocessors or vector processors to accelerate the computations. Because of gigantic data sizes, conventional forward-projection and back-projection are computed on the fly, and are implemented in two separate computing modules. This work describes an architecture that interleaves forward-projection and back-projection to enable a highly parallel processing on multi-core CPUs or GPUs. To improve the efficiency of the architecture, we split the system matrix or projection model into thousands of block matrices, and interleave forward-projection with back-projection for each block matrix. This architecture reduces memory requirement for computed sinogram by up to four orders of magnitude over conventional architecture optimized to forward- and back-projection separately. To reduce recurring computations in a back-projection, we reuse pre-computed values from the previous forward-projection, which achieves 2 times speedup over conventional separable footprint back-projection, implemented in an optimized single thread program on a 2.8GHz Intel CPU. For a 512x512x108 test image in an axial cone-beam X-ray CT system, we predict that more than 200 threads can work simultaneously to perform forward- and back-projection of a block matrix without downgrading the performance of the architecture.

This work was funded, in part, by the University of Michigan.
Structure of dynamic emotion estimates
Yelin Kim¹, Emily Mower Provost¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Automatic emotion recognition has grown rapidly in the past few decades with the growing attention and need for machinery that affectively interacts with humans. However, there are still many open questions on how to computationally represent and analyze human emotion. In this research, we focus on the structural fluctuation of emotion estimates. We calculate the relative similarity between two utterances using this estimated fluctuation to increase our understanding of the temporal unfolding of emotion-specific behaviors. This structure may provide the salient information highlighting the hidden internal state of a human user. To this aim, we investigate the intrinsic structure of human emotion fluctuation and propose a new framework for emotion classification that focuses on this estimated structure. We estimate the structure of emotion by tracking the presence or absence of basic emotion classes over the course of an utterance. We use similarity between these estimates of emotion flow to classify the affective state of input utterances. We demonstrate that estimates of structure can be used to recognize the emotion state of a given utterance. This result suggests that holistic structure estimates can be used to characterize emotional utterances.

This work was funded, in part, by Korea Institute of Energy Technology Evaluation and Planning.
System identification from low-dimensional objects
Joel LeBlanc$^{1,2}$, Brian Thelen$^2$, Alfred Hero$^1$

$^1$Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
$^2$Michigan Tech. Research Institute, Ann Arbor, MI

A joint-estimation framework is presented that exploits low-dimensional object representations to enable robust and accurate system identification from undersampled and misaligned data. Specifically, wavefront estimation is explored in the presence of under-sampling and an unknown imaging perspective, as well as unknown detector gain and offset, quantum efficiency, ambient light levels, target reflectance, and sensor read-noise. The physics-based, continuous-to-discrete forward-imaging model is sufficiently flexible to characterize loosely controlled imaging scenarios, making the proposed inverse-problem broadly applicable. A Maximum-Likelihood (ML) estimator is presented for both a known-object formulation, as well as ad-hoc objects containing multiple edges. Both estimators are shown to enable single-frame wavefront estimation, and experiments are shown which support these findings. For the known-object formulation, a computationally efficient form of the Cramér-Rao Bound (CRB) is derived, and the proposed estimator is shown to be within 1 dB of the bound under moderate SNR conditions.
Spherical harmonics based classification and analysis of highly deforming cells in 3D microscopy
Alexandre Dufour$^1$, Tzu-Yu Liu$^2$, Christel Ducroz$^1$, Alfred Hero$^2$ and Jean-Christophe Olivo-Marin$^1$

$^1$Institut Pasteur, Quantitative Image Analysis Unit, F-75015, Paris, France
$^2$Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Cell morphology is a key factor implicated in numerous biological processes, from organ development to disease models. Yet, characterizing highly deforming cells based on their morphology is particularly challenging due to the great variability of shapes within a given population. Our goal is to develop quantitative tools to classify highly deforming cells based on 3D shape information, and to extract key features describing the differences between populations in a qualitative manner. We introduce the use of Spherical Harmonics to extract 3D morphological information from cells observed in fluorescence microscopy. Group-based classification is achieved using Support Vector Machine with variable selection. We demonstrate our approach on two populations of Entamoeba histolytica parasites with visually indistinguishable morphology, and report a classification rate of 90%. Additionally, the variable selection process highlights several features discriminating the cell shape between the studied conditions, providing a novel insight into the parasite migration process.
Reducing Physiological Noise in Functional MRI by Model-Based Reconstruction
Matthew J. Muckley\textsuperscript{1}, Jeffrey A. Fessler\textsuperscript{2}, Douglas C. Noll\textsuperscript{1}

\textsuperscript{1}Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Functional magnetic resonance imaging (fMRI) is a powerful technique that has allowed neuroscientists and clinicians to study a myriad of brain functions in human subjects. These experiments rely on the blood oxygen level dependent (BOLD) effect, which creates local alterations in the magnetic field in response to upregulation and downregulation of metabolic needs due to neural activation. Functional connectivity experiments (fcMRI) are a type of fMRI experiment that attempt to identify neural networks of activation rather than more popular methods that simply use regression to well-known models. However, since fcMRI relies on temporal correlations, in many cases the most significant correlates are not the neural signals of interest, but rather the cardiac and respiratory rhythms. These signals must be removed to allow robust analysis of networks in functional connectivity studies. Since these physiological rhythms are sampled below their respective Nyquist frequencies, they cannot be removed using standard filtering. Here we propose a novel acquisition-reconstruction scheme based on a low rank model combined with temporal Fourier sparsity regularization. We demonstrate that the low rank model has the potential to reconstruct the space-time matrix sufficiently to filter physiological signals and generate correlation maps that are qualitatively similar to those acquired with higher temporal resolution.
A parameter-free augmented Lagrangian method for edge-preserving image restoration
Hung Nien¹, Jeffrey A. Fessler¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The augmented Lagrangian (AL) method (and its closely related cousin, the alternating direction method of multipliers, or in short, ADMM) is a powerful technique for solving ill-posed inverse problems with sparsity-promoting regularizers by using variable splitting. Although had received a lot of attention recently and usually been known as a "fast" method, this technique requires sophisticated parameter tuning in order to guarantee fast convergence. Even worse, the nontrivial parameter selection is application-dependent. That is, an experimentally optimized parameter for one application does not necessarily work well in another. This largely reduces the applicability of the AL method. In this paper, we first derive the optimal step size (or penalty parameter) for image restoration problems with Tikhonov regularization. Then, based on that, we propose an easy update scheme for the step size thus leading to a simple, parameter-free, AL-based algorithm for edge-preserving image restoration. Simulations show that the proposed algorithm converges fast in general, and the self-adjusting step size converges to a nearly optimal value rapidly. In other words, our proposed algorithm learns the (nearly) optimal step size on-line. Similar idea can also be applied to other applications involving the sparsity prior such as sparse learning and compress sensing.

This work was funded, in part, by NIH grant R01-HL-098686 and by an equipment donation from Intel.
Toward mutual Information based automatic registration of 3D point clouds
Gaurav Pandey¹, James R. McBride², Silvio Savarese¹, Ryan Eustice³

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
²Research and Innovation Center, Ford Motor Company, Dearborn, MI
³Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

Here we report a novel Mutual Information (MI) based algorithm for automatic registration of unstructured 3D point clouds comprised of co-registered 3D lidar and camera imagery. The proposed method provides a robust and principled framework for fusing the complementary information obtained from these two different sensing modalities. High-dimensional features are extracted from a training set of textured point clouds (scans) and hierarchical k-means clustering is used to quantize these features into a set of codewords. Using this codebook, any new scan can be represented as a collection of codewords. Under the correct rigid-body transformation aligning two overlapping scans, the MI between the present codewords is maximized. We apply a James-Stein-type shrinkage estimator to estimate the true MI from the marginal and joint histograms of the codewords extracted from the scans. Experimental results using scans obtained by a vehicle equipped with a 3D laser scanner and an omnidirectional camera are used to validate the robustness of the proposed algorithm over a wide range of initial conditions. We also show that the proposed method works well with 3D data alone.

This work was funded, in part, by Ford Motor Company via Ford-UofM Alliance.
Image reconstruction from a Manhattan grid via piecewise plane fitting and Gaussian Markov random fields
Matthew A. Prelee¹, David L. Neuhoff¹, Thrasyvoulos N. Pappas²

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
²Department of Electrical Engineering and Computer Science, Northwestern University, Evanston, IL

In this work, the authors consider image reconstruction problems in which samples are taken on evenly spaced rows and columns, i.e., a Manhattan grid. A new reconstruction method is proposed that uses three steps to interpolate the interior of each block under the model that an image can be decomposed into piecewise planar regions plus noise. First, the K-planes algorithm is developed in order to fit several planes to the observed pixel values on the border. Second, one of the K planes is assigned to each pixel of the block interior, by a process of partitioning the block with polygons, thereby creating a piecewise planar approximation. Third, the interior pixels are interpolated by modeling them as a Gauss Markov random field whose mean is the piecewise planar approximation just obtained. The new method is shown to improve significantly upon previous methods, especially in the preservation of “soft” image edges.

The work of the first two authors was supported by NSF Grant CCF 0830438.
Jointly learning and selection features via conditional pointwise mixture RBMs
Kihyuk Sohn¹, Guanyu Zhou¹, Honglak Lee¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Feature selection is an important technique for finding relevant features from high-dimensional data. However, the performance of feature selection methods is often limited by the raw feature representation. On the other hand, unsupervised feature learning has recently emerged as a promising tool for extracting useful features from data. Although supervised information can be exploited in the process of supervised fine-tuning (preceded by unsupervised pre-training), the training becomes challenging when the unlabeled data contain significant amounts of irrelevant information. To address these issues, we propose a new generative model, the conditional point-wise mixture restricted Boltzmann machine, which attempts to perform feature grouping while learning the features. Our model represents each input coordinate as a mixture model when conditioned on the hidden units, where each group of hidden units can generate the corresponding mixture component. Furthermore, we present an extension of our method that combines bottom-up feature learning and top-down feature selection in a unified way, which can effectively handle irrelevant input patterns by focusing on relevant signals and thus learn more informative features. Our experiments show that our model is effective in learning separate groups of hidden units (e.g., that correspond to informative signals vs. irrelevant patterns) from complex, noisy data.
The performance of MUSIC-Based DOA in white noise with missing data

Raj Tejas Suryaprakash¹, Raj Rao Nadakuditi¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The Multiple Signal Classification (MUSIC) algorithm is widely used for estimating the direction of arrival (DOA) of signals impinging on a sensor array. Here we present an analysis of the performance of the MUSIC (and MUSIC-like) algorithms in the large array setting, where we have relatively few signal-plus-white-noise samples, or snapshots, and where we observe each element in the data matrix with a uniform probability. We use random matrix theory to obtain a closed-form, minimal stochastic equivalent representation for the DOA estimation error, which allows us to analyze the performance of the algorithm given the system parameters. This minimal representation facilitates accurate computation of the DOA mean squared error (MSE) and other desired statistics. Our analysis brings into sharp focus the presence of a phase transition boundary that separates a regime where MUSIC-based algorithms accurately localize a source, from a regime where the source is present but the algorithms fail to localize it. This critical phase transition threshold depends on the number of sensors, the number of samples and the probability of observing an entry of the data matrix in a simple manner that we make explicit. We validate our asymptotic theoretical predictions with simulations on moderately sized systems. We compare our theoretical performance prediction to that in previous literature, for the case when all data is observed, and demonstrate that we are better able to predict the DOA performance in the relatively low SNR regime. We also show that our predictions are accurate in the missing data setting.

This work was supported by the ONR Young Investigator Award N00014-11-1-0660.
Estimating the aspect layout of object categories
Yu Xiang¹, Silvio Savarese¹

¹Department of Computer Science and Electrical Engineering, University of Michigan, Ann Arbor, MI

In this work we seek to move away from the traditional paradigm for 2D object recognition whereby objects are identified in the image as 2D bounding boxes. We focus instead on: i) detecting objects; ii) identifying their 3D poses; iii) characterizing the geometrical and topological properties of the objects in terms of their aspect configurations in 3D. We call such characterization an object's aspect layout. We propose a new model for solving these problems in a joint fashion from a single image for object categories. Our model is constructed upon a novel framework based on conditional random fields with maximal margin parameter estimation. Extensive experiments are conducted to evaluate our model's performance in determining object pose and layout from images. We achieve superior viewpoint accuracy results on three public datasets and show extensive quantitative analysis to demonstrate the ability of accurately recovering the aspect layout of objects.

This work was funded by the ARO grant W911NF-09-1-0310, NSF CPS grant #0931474 and a KLA-Tencor Fellowship.
Local radius index – a new texture similarity feature
Yuanhao Zhai\textsuperscript{1}, David L. Neuhoff\textsuperscript{1}, Thrasyvoulos N. Pappas\textsuperscript{2}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Electrical Engineering and Computer Science, Northwestern University, Evanston, IL

We develop a new texture similarity feature, Local Radius Index (LRI), which can be used to quantify structural texture similarity of images based on human perception. Image similarity metrics based on LRI can be applied to structurally lossless image compression, identical texture retrieval and other related applications. For each texture pattern, LRI captures edge information in different directions, as well as the size of texture elements, by simple pixel value comparison in the space domain. Its simplicity is one of the main advantages of LRI, especially for many real-time applications. Better performance can be achieved if LRI is combined with other texture similarity features, such as Local Binary Pattern (LBP) [T. Ojala et al. 2002] and contrast information. By careful design, no extra computation is needed to compute the LBP and contrast features. Compared with Structural Texture Similarity Metric 2 (STSIM2) [Zujovic 2009], an LRI based metric achieves better retrieval performance with much simpler computation for a database containing 1181 texture images of 485 classes. The LRI metric is also tested on the CUReT and Brodatz databases with satisfying results. When applied to the recently developed structurally lossless image compression method, Matched Texture Coding (MTC) [Jin, et al., 2012], LRI enables lower coding rate with comparable compression quality and significantly accelerates the algorithm by up to 10 times, which is very important because the original MTC with STSIM2 is computationally expensive.
Solid State Materials and Physics

Session Chair: Eric Kai-Hsiang Yu
Air deposited, nano-structured organic semiconductor films and devices by guard flow-enhanced organic vapor jet printing
Shaurjo Biswas¹, Max Shtein¹

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

Small molecular organic semiconductor materials and devices enable the deposition of molecules at lower temperatures and on a greater variety of substrates as compared to conventional inorganic semiconductors. Traditionally, small molecular organic thin films are grown by vacuum thermal evaporation (VTE), a method limited in scalability when tight control of the stoichiometry and patterning is required. We recently demonstrated atmospheric, solvent free printing of the organic semiconductors in air using a modified organic vapor jet printing (GF-OVJP), in which a carrier gas transports sublimated organic vapor towards the substrate in the form of a focused jet, surrounded by an annular inert guard flow jet to prevent degradation of the heated material due to ambient oxygen and moisture. This approach enables additive patterning of organic semiconductors and can enhance the crystallization at low substrate temperatures. In addition, the apparatus is extremely compact, inexpensive and has six independently adjustable process parameters to achieve tight control of deposited film morphology. Here, we demonstrate the growth of polycrystalline molecular organic thin films in air by this technique, and study their performance in optoelectronic devices, including organic photovoltaics, light emitting diodes, and thin film transistors. The enhancement of solar-cell and organic LED performance is demonstrated as a function of guard flow rate, which appears to mitigate parasitic oxidation of the organic and control roughness and crystallinity of the organic vapor jet-grown films, ultimately achieving parity with VTE-grown analogues. The poster further explores the relation of processing parameters to deposited film morphology and thus device performance.

This work was funded, in part, by Air Force Office of Scientific Research, National Science Foundation and US Department of Energy.
Dilute oxygen incorporation in ZnTe by plasma-assisted molecular beam epitaxy

C Chen, S Kim, J Phillips, X Pan

University of Michigan, Ann Arbor, Michigan 48109

Highly mismatched alloys (HMA) are semiconductor alloys whose anions are highly mismatched in electronegativity. The localized nature of the anions’ electronic states potentially exhibit band anti-crossing effects, which have been proposed to describe some interesting material properties of HMAs, such as large bandgap bowing, deep level traps, or an intermediate band. These properties have been proposed for applications in energy conversion devices such as thermoelectrics and intermediate band solar cells. This work focuses on the growth of ZnTe:O using plasma-assisted MBE, and the resulting chemical, electronic, and optical properties. ZnTe is a wide bandgap II-VI material with bandgap of 2.3eV, where oxygen substitution on a tellurium site introduces a deep isoelectronic state near 1.8eV above the valence band. The materials are grown by molecular beam epitaxy on GaAs (100) and GaSb (100) substrates, with solid sources of Zn and Te, and an ECR plasma source for oxygen. Varying degrees of oxygen incorporation were introduced by controlling beam equivalent pressure (BEP) for oxygen in the range of 2x10^7 Torr to 2x10^5 Torr. Oxygen incorporation may also be controlled by varying the ZnTe growth rate, where nominal growth conditions include a growth rate of 0.5 microns/hour and a VI/II BEP ratio of 1. Structural characterization including x-ray diffraction and transmission electron microscopy indicate an epitaxial relationship between the ZnTe(O) and III-V substrates. Secondary ion mass spectroscopy (SIMS) data shows that the different growth conditions result in oxygen doping concentration on the order of 10^18 cm^-3 to 10^19 cm^-3, whereas nuclear reaction analysis measurements indicates an oxygen concentration of approximately 10^20 cm^-3 for all growth conditions. SIMS analysis on a sample grown with multiple layers of variable oxygen content shows diffused oxygen profiles indicating that oxygen diffusion can be significant at typical growth temperatures of 300°C. Photoluminescence (PL) measurements demonstrate strong subbandgap emission with intensity that increases with oxygen concentration. For low oxygen concentration, subbandgap emission is observed near 1.9eV (at T=20K) with clearly observed phonon replicas. Increasing oxygen content results in a shift of the subbandgap PL to 1.8eV (at T=20K) and a quenching of the bandedge ZnTe emission. The decrease in the peak emission energy for the subbandgap emission suggests the presence of band anti-crossing effects. The implications of the optical properties on future devices such as the intermediate band solar cell will be briefly discussed.
Zinc tin oxide (ZTO) is a promising transparent amorphous oxide semiconductor (TAOS) for low cost and large area display applications. Solution-processed ZTO semiconductor thin films are made using inks of zinc acetate dehydrate and tin (II) acetate in 2-methoxyethanol, with various Zn:Sn ink ratios and various annealing temperatures. The resulting three-layer ZTO thin films have total thickness of 72 nm. They are amorphous and non-porous, with a very smooth surface (rms surface roughness of 1.5 nm). Using this process, a ZTO layer and metal electrodes are deposited on silicon-silicon dioxide substrates and patterned to form bottom gate, top contact thin film transistors (TFTs). The best TFT devices exhibit room temperature field-effect mobility of 2.7 cm²/(V·s) and on-off current ratio of 5×10⁶. Cryogenic electrical measurements from 77K to 300K are conducted to quantitatively study the charge transport mechanisms and sub-bandgap density of states. Percolation conduction and Fermi level pinning are observed in all TFTs. The shape and energy levels of the band structure can be engineered by adjusting fabrication conditions such as annealing temperature and stoichiometry. The percolation energy and Arrhenius energy are as low as 3.2 meV and 7 meV, respectively, for optimal TFTs, which are fabricated with Zn:Sn ink ratio of 7:3 and 480°C annealing temperature. The sharpness of the band-tail states correlates well with the large room temperature electron mobility, and is comparable to that measured by other groups for vacuum-processed ZnO-based TFTs.

This work was supported by National Science Foundation Grant ECCS #1032538. Portions of this work were performed in the Lurie Nanofabrication Facility.
Electronic and optical characteristics of type-II GaSb/GaAs quantum dots for intermediate band solar energy conversion

Jinyoung Hwang\textsuperscript{1}, Andrew J. Martin\textsuperscript{2}, Joanna M. Millunchick\textsuperscript{2}, and Jamie D. Phillips\textsuperscript{1}

\textsuperscript{1}Dept. of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

Intermediate band solar cells (IBSC) have been developed to surmount the Shockley-Queisser limit of a single junction solar cell by accommodating sub-bandgap photon absorption via absorption bands within the band gap of the host material while preserving the open circuit voltage (Voc). The intermediate band (IB) can be introduced by confined states in quantum dots (QDs), where InAs/GaSb QD-IBSCs have demonstrated sub-bandgap response and enhancement in photocurrent. However, significant increases in conversion efficiency have not been achieved in the type-I QD system due to mismatch in optical transition rates associated with the IB (fast transition rate from the IB to conduction band and slow transition rate from valence band to the IB) and excessive thermal emission rate of carriers in QDs. GaSb/GaAs QDs with a type-II band alignment are proposed to mitigate these problems, where the electronic and optical properties of the materials relevant for intermediate band solar energy conversion are reported in this work. Optical transition rates via the IB in the GaSb/GaAs QD system are calculated by k.p method including Coulomb effect between carriers in a QD. A reduced oscillator strength is calculated for optical transitions between confined hole states in the QD valence band and the conduction band due to the spatial separation of electron/hole wavefunctions in the type-II structure. The reduced rate provides a tradeoff and better match to the intraband transitions in the valence band. The thermal emission rates of carriers in GaSb/GaAs QDs are measured using admittance spectroscopy, where significantly lower rates are observed in comparison to InAs/GaAs QDs suggesting that optical transition rates can be the dominant process for the intersubband transitions under solar concentration in a GaSb/GaAs IBSC. The overall picture of carrier dynamics associated with optical and thermal generation rates in the GaSb/GaAs QD system will be presented and discussed with their relevancy to IBSC operation. The photoresponse and temperature-dependent current-voltage behavior of GaSb/GaAs QD IBSCs will be discussed and analyzed according to optical and thermal transition rates.

This work was funded, in part, by the Center for Solar and Thermal Energy Conversion, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences.
An all-graphene flexible and transparent circuit for quaternary digital modulation
Seunghyun Lee¹, Kyunghoon Lee¹, Chang-Hua Liu¹, Girish S. Kulkarni¹ and Zhaohui Zhong¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Nearly all flexible electronic devices require an external data communication modules, and without the integration of this part, the lack of portability can severely limit the functionality of various applications. However, developing a wireless communication system with conventional flexible materials such as organic polymers, amorphous silicon, or oxide-based thin film transistors is still a challenge due to their limited carrier mobilities. Graphene, an atomic layer thick carbon sheet, is an ideal material for flexible high speed communication systems due to its high carrier mobility (>1000 cm²/Vs), ambipolarity, transparency, and mechanical flexibility. In this work, we demonstrate, for the first time, flexible and transparent all-graphene circuits for quaternary digital modulations that can encode two bits of information per symbol. The entire circuits including the transistor channels, the interconnects between transistors, the load resistance, and the source/drain/gate electrodes are fabricated with graphene only. No other metal or semiconductor was used. This structure is possible due to graphene's unique property of being a zero-bandgap material retaining the property of both metal and semiconductor. The monolithic structure allows unprecedented mechanical flexibility and near-complete transparency (~95%). In addition, the ambipolarity of graphene transistors drastically reduces the circuit complexity when compared with silicon-based modulators. The operating principle and technique of flexible and transparent all-graphene modulators described here can be applied to widely used network technologies in today's communication devices. In conjunction with conventional thin film technology and high resolution lithography, graphene material will play a pivotal role in realizing a high speed, mechanically compliant, and transparent electronic system in the near future.

This work was funded, in part, by the National Science Foundation Scalable Nanomanufacturing Program (DMR-1120187).
Evidence for extraction of photoexcited hot carriers from graphene
Chang-Hua Liu¹, Nanditha M. Dissanayake¹, Seunghyun Lee¹, Kyunghoon Lee¹, and Zhaohui Zhong¹

¹Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

For conventional bulk semiconductors, hot carriers created by high energy photons will quickly cool to the band edge. This thermalization process causes a substantial amount of photon energy loss to the lattice, and limits the fundamental efficiency of optoelectronic devices. Graphene could be the potential material for making hot carrier devices based on its unique electrical and optical properties. We observe photocurrent generation in graphene/metal junction induced by nonequilibrium hot carriers. The photoresponse of graphene device excited by femtosecond pulse laser shows unusual gate dependence compared with continuous wave (CW) laser excitation. This unusual photoresponse is due to nonequilibrium hot carrier extraction, which can be confirmed by our laser power dependence studies. In addition, hot carrier extraction is found to be most efficient when operating the graphene device near the Dirac point, where carrier lifetime reaches a maximum. These fundamental observations would open the door for developing graphene based hot carrier optoelectronics.

This work was funded by the American Chemical Society Petroleum Research Fund, the U-M/SJTU Collaborative Research Program in Renewable Energy Science and Technology, and National Science Foundation Scalable Nanomanufacturing Program (DMR-1120187).
Blast-Wave Mitigation Efficiency of the Multilayered Advanced Combat Helmet
Tanaz Rahimzadeh, Ellen Arruda, Michael Thouless

Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

In the current US military, the Advanced Combat Helmet (ACH) is one of the main pieces of equipment used for head protection against blast and ballistic loading. Considering the current ACH design, being near an explosion (blast) can still produce a range of injuries called Traumatic Brain Injury (TBI). TBI is generally considered as the signature injury of the current military conflicts involving costly and life-altering long-term effects. Hence, there is an urgent need to battle this problem first by gaining a better understanding of the mechanisms responsible for the blast-induced TBI and second by designing/developing more effective head protection systems. In the present work, blast-induced TBI were reviewed from biological point of view and linked to several influencing mechanical parameters. Then several alternatives for the mitigation of the defined influencing mechanical parameters were explored such as impedance mismatch, energy dissipation through plasticity in irreversible crushable foams and finally stress relaxation concept and frequency tuning in visco-elastic materials. Using a systematic design optimization methodology, some potential multilayered ACH designs were proposed and their TBI mitigation capabilities were investigated using Finite Element Analysis (FEA).

This work was funded, in part, by ONR.
Simulation and characterization of ZnTe:O-based intermediate band solar cells

Alan S. Teran\textsuperscript{1}, Chih-Yu Chen\textsuperscript{2}, Jinyoung Hwang\textsuperscript{1}, Jamie Phillips\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Applied Physics Program, University of Michigan, Ann Arbor, MI

Solar cells have garnered a lot of attention due to the rising cost of fossil fuels and the increasing global demand for renewable sources of energy. In order to provide the lowest cost for electricity ($/Watt) and to minimize the use of land area, higher efficiency solar cells are needed. The efficiency of traditional single junction solar cells are limited by the bandgap energy of the absorbing material, resulting in a theoretical limiting efficiency of approximately 30\%. The intermediate band solar cell (IBSC) takes advantage of sub-bandgap energy levels to absorb a larger portion of the solar spectrum. By introducing an energy state within the bandgap, photons of three different energy ranges can be absorbed, providing a theoretical limiting efficiency of approximately 63\%. The ZnTe:O alloy has been shown to be a promising candidate as an intermediate band (IB) material due to the deep energy states provided by oxygen doping. The oxygen doping level lies 0.5 eV below the conduction band, allowing for the absorption of photons with wavelengths approximately 2.5 μm, 700 nm, and 500 nm. In this work we present simulation results for the theoretical performance of ZnTe:O-based IBSCs as well as experimental characterization of our solar cell devices. Multi-source IV measurements show sub-bandgap response for light sources with wavelengths 635 nm and 2.4 μm, confirming the behavior of IBSCs. Temperature dependent IV (TIV) measurements provide improved understanding of the effect on open circuit voltage (Voc) and short circuit current (Jsc) by the IB.

\textit{This work was funded, in part, by NSF and DOE.}
Directed matrix seeding of embedded semiconductor nanocomposites for high efficiency thermoelectrics

M. V. Warren¹, G. Wang², V. A. Stoica³, R Clarke³, C. Uher²,³, R. S. Goldman¹,²,³

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
²Department of Physics, University of Michigan, Ann Arbor, MI
³Department of Applied Physics, University of Michigan, Ann Arbor, MI

Nanocomposite materials have been identified as promising candidates for high figure-of-merit thermoelectric materials. Due to the increased control of the density of states and hence, the energies of charge carriers, nanocomposite materials are predicted to have a significantly higher thermoelectric power factor ($S^2\sigma$, where $S$ is the Seebeck coefficient and $\sigma$ is the electrical conductivity) compared to bulk materials. Nanoscale inclusions of metallic and semi-metallic particles are predicted to enhance the Seebeck coefficient via electron energy filtering. One approach to nanocomposite synthesis is matrix-seeded growth, which involves ion-beam-amorphization of a semiconductor film, followed by nanoscale re-crystallization via annealing. We recently showed that indium ion implantation into GaAs, followed by thermal annealing, leads to an enormous increase in the GaAs Seebeck coefficient. Annealing these films at high temperatures (600°C) results in recrystallization of the amorphous layer without nanocrystal formation. For the lowest annealing temperatures (450°C), metallic indium nanocrystals nucleate within the amorphous GaAs matrix, which in turn enhance the Seebeck coefficient by 25% at room temperature. Similarly, bismuth ion implantation into GaAs leads to the formation of an amorphous layer containing crystalline remnants; upon annealing, metallic Bi nanocrystal formation is expected. We will discuss measurements of the nanostructure, Seebeck coefficient, electrical resistivity, and thermal conductivity of both In- and Bi-implanted GaAs films. Together, these measurements allow us to examine correlations between the nanostructure and the thermoelectric figure of merit, providing new insights into the potential of embedded semiconductor nanocomposites for thermoelectrics.

This material is based upon work supported as part of the Center for Solar and Thermal Energy Conversion, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0000957.
Functionalized squaraine donors for nanocrystalline organic photovoltaics
Xin Xiao\textsuperscript{1}, Jeramy D. Zimmerman\textsuperscript{1}, Guodan Wei\textsuperscript{2}, Siyi Wang\textsuperscript{3}, Mark E. Thompson\textsuperscript{3}, Stephen R. Forrest\textsuperscript{1,2,4}.

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Department of Chemistry, University of Southern California, Los Angeles, CA
\textsuperscript{4}Department of Physics, University of Michigan, Ann Arbor, MI

Organic photovoltaics (OPV) has attracted intensive research interest due to its promising potential as a candidate of low-cost, light-weight and flexible sources for renewable energy. New donor material is essential to achieve high-efficiency OPV. Functionalized squaraines (SQ) are promising candidates of donors due to their large absorption coefficients and deep HOMO levels. Recently, we demonstrated an efficient OPV devices based on parent SQ. However, it still suffers from a low charge carrier mobility due to poor intermolecular stacking. Here, by attaching planar molecular groups to the core SQ molecule, we develop molecular structures that have a tendency to stack more tightly. Specifically, three symmetric, 1-NPSQ, DPSQ and PSQ, and two asymmetric molecules, DPASQ and ASSQ, were studied for OPV devices. The solution-processed functionalized SQ OPV device, paired with the acceptor, \textit{C}_60, has an open circuit voltage as high as 1.0V and fill factor up to 0.73. By thermal annealing of the deposited films, 1-NPSQ/\textit{C}_60 OPV devices have achieved a power conversion efficiency (PCE) of 5.7±0.6\% under one sun illumination. To correlate the device performance with physical properties, we also studied the morphology, crystallinity, density and exciton diffusion lengths of new SQ donors. Our study suggests that new functionalized SQ donors are promising for high efficiency small-molecule OPV devices.

\textit{This work was funded, in part, by the Center for Solar and Thermal Energy Conversion at the University of Michigan, the Air Force Office of Scientific Research, Global Photonic Energy Corp.}
High efficient flexible Cu(In,Ga)Se$_2$ solar cells fabricated on stainless steel substrate by metallic precursor sputtering based roll-to-roll process

Rui Zhang$^1$, Dennis R. Hollars$^2$ and Jerzy Kanicki$^1$

$^1$ Solid State Electronic Laboratory, Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109, U.S.A.
$^2$ NuvoSun Inc., Milpitas, CA 95035, U.S.A.

We reported on a Cu(In,Ga)Se$_2$ (CIGS) solar cell fabricated on flexible stainless steel substrate by a low cost mass production process having a high energy conversion efficiency of ~14%, with short circuit current density ($J_{sc}$) of 36.6mAcm$^{-2}$ and open circuit voltage ($V_{oc}$) of 0.55V. CIGS layer was prepared by sputtering metallic precursors In:CuGa and then annealing in Se vapor. Secondary ion mass spectrometry (SIMS) and transmission/scan electron microscopy (TEM/SEM) analysis were performed to evaluate its chemical properties. Indium (In) and gallium (Ga) interdiffusions were observed during the growth of film, forming a normal band grading in CIGS layer. Accumulation of In at the surface, resulting in a low bandgap, was responsible to the limited output open circuit voltage, supported by quantum efficiency measurement results. Nano-scale voids were observed in the grown CIGS layer. A model based on Kirkendal effect and interdiffusion of atoms during selenization is used to explain the forming mechanism of these voids. Na and K incorporation as well as metallic impurities diffusion were also discussed. In addition, a 2D modeling of CIGS solar cell as a baseline was established showing that both experimental and calculated data are consistent with each other.
Space Research and Aerospace Engineering

Session Chair: Jacob Davidson
Computational modeling of surface catalysis for graphite exposed to high-enthalpy flows
Abhilasha Anna¹, Iain D. Boyd¹.

¹Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Many of the missions aimed towards space exploration require an entry into the atmosphere of Earth or another planet at hypersonic speeds. These atmospheric entry probes, i.e. hypersonic vehicles, experience significant heat loads during (re-)entry that cause very high temperatures on their surface. Therefore, such vehicles use a Thermal Protection System (TPS) for protection from aerodynamic heating. TPS being a single point of failure system requires a good understanding of the physical and chemical processes essential for its design. Surface catalysis is a crucial chemical process that directly impacts aerothermal heating of the vehicle TPS. The effects of surface catalysis on the numerical solution for a graphite sample exposed to high-enthalpy nitrogen flow are examined in this study using different values of catalytic efficiency. The objective of this research is to investigate and implement surface chemistry models to describe dominant gas-surface processes. To account for the full range of catalycity regimes, from a non-catalytic wall to a fully-catalytic wall, a binary catalytic atom recombination model is implemented in the Michigan Aerothermodynamics Navier-Stokes computational fluid dynamics (CFD) code LeMANS, developed at the University of Michigan. Assessment of the computations is performed using experimental tests that were conducted in the 30 kW Inductively Coupled Plasma (ICP) Torch Facility at the University of Vermont. Strong surface catalysis effects on the boundary layer gradients of species concentration and heat transfer to the surface are observed.

This work was funded, by [Air Force Office of Scientific Research Grant FA-9550-11-1-0309].
Exploring the use of miniaturized electrodynamic tethers to enhance the capabilities of ultra-small satellites

Iverson C. Bell, III1 and Brian E. Gilchrist1

1Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

The success of nanospacecraft (1-10 kg) and the evolution of the millimeter-scale wireless sensor network concept (i.e., “SmartDust”) have generated interest in small, sub-kilogram scale, “smart-phone” sized spacecraft, either as stand-alone satellites or as elements in a maneuverable fleet. Distributed fleets of ultra-small satellites, sometimes called “ChipSats”, would require a high level of coordination, and this requires maneuverability and propulsion. We summarize previous trade studies in which we investigated the use of a very short (few meters), semi-rigid electrodynamic tether (EDT) for femtosatellite propulsion. The system concept utilizes an insulated tether and a pair of nearly identical pico- or femtosatellites capable of harvesting solar energy, storing electrical power, and collecting and emitting electrons. The results reveal that an insulated tether, only a few meters long and tens of microns in diameter, can provide milligram to gram-level ChipSats with complete drag cancellation and even the ability to change orbit. Further, a few meter tether could also serve as a communications or a scientific radio antenna, serves as a plasma diagnostics probe, and even a boom for passive attitude stability along the local vertical. Here, we build on the previous trade study and demonstrate, through a proposed experiment, that the EDT system is capable of collecting sufficient current and generating the Lorentz force required for propulsion. We describe a ground-based plasma chamber experiment in which the key plasma parameters scale with ionospheric plasmas. We also describe experiments focused on understanding how the system can be used to enhance ultra-small satellite communication.

This material is based upon work supported by the National Science Foundation Graduate Student Research Fellowship under Grant No. DGE 1256260 and AFOSR grant FA9550-09-1-0646.
Virtual observations for multi-species ion distributions at Mars
S. Curry¹, M. Liemohn¹, X. Fang², and Y. Ma³

¹University of Michigan, Ann Arbor, MI
²University of Colorado, Boulder, CO
³University of California, Los Angeles, CA

This study focuses on using the Mars Test Particle simulation to investigate observations of O+, O2+, CO2+, and H+ in an orbital configuration in the Mars space environment. These virtual observations address the broader effort to better understand atmospheric evolution and water removal from Mars’ atmosphere, specifically with respect to nonthermal atmospheric loss. Due to the lack of an intrinsic dipole magnetic field, pick-up ions are a main source of nonthermal atmospheric loss and are formed when the solar wind directly interacts with the neutral atmosphere, causing the ions to be accelerated away by the background convective electric field. Previous modeling efforts and observations have found different results regarding which species is most dominant in atmospheric escape; some conclude that O+ is the most dominant escaping ion while others conclude that O2+ has the larger total loss rate. Furthermore, mass loss might actually favor CO2+ because of its tri-atomic structure. To address this unresolved issue, this study will present velocity space distributions for different species and discuss fluxes and escape rates using different modeling parameters. The simulation will also be the first to illustrate individual species’ particle traces, which reveal the origin and trajectories of the different ion species. Finally, results from different solar conditions will be presented with respect to ion fluxes and energies as well as overall escape in order to describe the physical processes controlling planetary ion distributions and atmospheric escape.
MESSENGER observations of magnetopause structure and dynamics at Mercury

Gina A. DiBraccio¹, James A. Slavin¹, Scott A. Boardensen²,³, Brian J. Anderson⁴, Haje Korth⁴, Thomas H. Zurbuchen¹, Jim M. Raines¹, Daniel N. Baker⁵, Ralph L. McNutt, Jr.⁴, and Sean C. Solomon⁶

¹Dept of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI
²Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD
³Goddard Planetary Heliophysics Institute, University of Maryland, Baltimore County, MD
⁴The Johns Hopkins University Applied Physics Laboratory, Laurel, MD
⁵Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO
⁶Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY

MESSENGER observations during the first three Mercury years of orbit (one Mercury year equals 88 Earth days) have been used to characterize the structure of Mercury’s dayside magnetopause as a function of magnetic field properties in the incident magnetosheath. Measurements collected by MESSENGER’s Magnetometer and Fast Imaging Plasma Spectrometer yielded a minimum of two dayside magnetopause encounters per day due to the 12-h orbit of the spacecraft during this interval. After applying a minimum variance analysis (MVA) to all distinct boundary crossings, we further examined only those with an intermediate to minimum eigenvalue ratio greater than 5. For the 43 events meeting this criterion, we determined (1) the normal component of the magnetic field across the current sheet, from which we inferred the rate of reconnection, (2) the temporal duration and, with certain assumptions, the speed and thickness of the magnetopause, and (3) the reconnection rate as a function of magnetic shear angle and plasma beta (the ratio of total thermal pressure to magnetic pressure) across the boundary. In boundary-normal coordinates we identified an average normal magnetic field component of 20 nT, enabling the entry of solar wind plasma into the magnetosphere. The magnetopause velocity is estimated to be on the order of 10 km s⁻¹ by assuming a current sheet thickness of 7 times the gyroradius of a 1 keV solar wind proton. From this result we infer the average boundary thickness to be 49 ± 7 km, which is comparable to ~3 proton gyroradii. For a magnetosheath flow of 200 km s⁻¹ and a reconnection X-line length of 3 RM, we calculate an average electric potential drop of 29 kV at the magnetopause. The rate of reconnection, the ratio of the normal magnetic field component to the total field magnitude just inside the magnetopause, is measured to be 0.15 ± 0.02. This rate, which is approximately one order of magnitude larger than typical Earth observations, is determined to be independent of magnetic field shear angle. However, in agreement with theoretical predictions, the reconnection rate at Mercury does increase strongly as magnetosheath plasma beta decreases.
GeoMACH: geometry-centric MDAO of aircraft configurations with high fidelity
John T. Hwang$^1$ and Joaquim R. R. A. Martins$^1$

$^1$Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

With state-of-the-art computational tools, it is now possible to simultaneously optimize the shape and sizing of commercial aircraft across multiple operating conditions. Parallel computing and efficient algorithms allow optimization with respect to hundreds of design variables using coupled CFD and FEA involving millions of state variables. The objective of this work is to bring these optimization tools earlier in the aircraft design process using GeoMACH: Geometry-centric MDAO of Aircraft Configurations with High fidelity. GeoMACH is an open-source aircraft design tool suite under development that enables multidisciplinary design, analysis, and optimization (MDAO) of aircraft in conceptual and preliminary design through three components. First, an efficient and lightweight B-spline engine has been developed for modeling geometry and facilitating communication of data between disciplines. It implements a geometry-centric approach to MDAO through a novel representation of variables that simplifies data transfer between different meshes. Second, a unique tool for modeling the aircraft’s outer mold line (OML) is a key enabling component, spanning a configuration-level design space while maintaining an elegant parametrization and differentiable mappings. Finally, a parametric structural modeler has also been developed for automatically generating an OML-driven model of the detailed aircraft structure, including the skin, spar, ribs, stringers, frames, and longerons. The expected significance of this work is in the development of an integrated framework for aircraft conceptual design that has the potential to allow high-fidelity MDAO to make a large impact on the aircraft design process.

This work was funded, in part, by NASA’s Subsonic Fixed Wing project.
Similarities and differences in low-to-mid latitude geomagnetic indices during storms
Roxanne M Katus¹ and Michael W. Liemohn¹

¹Department of Atmospheric, Oceanic and Space Science, University of Michigan, Ann Arbor, MI

Several versions of low-to-middle latitude geomagnetic indices are examined with respect to a normalized timeline based on several key storm features. In particular, we examine the well-known Dst and SYM-H indices, as well as a few other more recently-developed storm-intensity indices. These superposed indices are quantitatively compared, using the bootstrap method to quantify the error analysis, and employing descriptive statistics and significance tests to assess the similarities and differences between them. The results are then categorized by storm intensity, storm phase, and solar wind driver. While the indices are highly correlated with each other, dramatic deviation between the indices exist at certain storm epoch times and for certain types of magnetic storms. In particular, the correlation degrades at storm peak and especially for more intense storms. These indices are compared against simulation results from the Hot Electron and Ion Drift Integrator (HEIDI) model, which has been run for every intense storm from the last solar cycle with several input and boundary condition settings. Current systems and magnetic perturbations from these simulation results, which are also scaled onto a normalized storm-based timeline and categorized by storm intensity, storm phase, and solar wind driver, are used to interpret the physical processes underlying the systematic differences in the various ground-based magnetometer indices.
Simulation of using background plasma to neutralize charged particle thrusters on nanospacecraft

David Liaw\textsuperscript{1}, Thomas Liu\textsuperscript{2}, Brian Gilchrist\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

There is an emerging class of nanospacecraft thrusters that use colloids or nanoparticles that can be charged either positively or negatively to provide thrust. An issue to be examined is how to neutralize both the spacecraft and the emitted beam. We focus on the capabilities of the nanoparticle field extraction thruster (NanoFET) to self-neutralize. Previously, we have explored two approaches for charged particle thruster neutralization: spatially and temporally separated oppositely charged populations of nanoparticles. Both solutions would result in equal amounts of both charged populations being emitted, in theory resulting in a charge neutral spacecraft and beam. However, in reality, when dealing with such large, heavy, equally “massive” particles of opposite polarities, it is difficult to get them to interact in a relatively short time span and self-neutralize. On the other hand, at the relatively low power levels that a nanospacecraft will be operating at, 25 W at a 50\% duty cycle, it is quite possible that a singly charged beam will be running at a low enough current to provide the propulsion needed as well as be sufficiently neutralized by the ambient space plasma thus negating all detrimental effects of a charged spacecraft and charged beam. In this presentation, we briefly discuss the NanoFET system, as well as previous attempts to self-neutralize using oppositely charged particles. In addition, there is an in-depth analysis, including simulations using OOPIC PRO\textsuperscript{TM}, of a singly charged beam being emitted into an ionospheric plasma which neutralizes the emitted beam as well as the spacecraft.
Earth's ground-based magnetic perturbations in response to substorms
Nicole Pothier

Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI

Large-scale maps of the surface perturbations in the Earth's magnetic field following the onset of substorms have been produced for use in improving prediction models of surface effects due to space weather. Data from 124 ground magnetometer stations in the northern hemisphere at geomagnetic latitudes greater than 33.4 degrees were used. Upstream interplanetary magnetic field (IMF) data from the Advanced Composition Explorer (ACE) satellite were also used for sorting ground magnetometer data by orientation of the IMF. Both datasets were compiled into 5-minute increments for an eight-year time period (1998-2005). Pseudo-Auroral Upper (AU), Auroral Lower (AL), and Auroral Electrojet (AE) indices were calculated from these data for the eight-year period. These indices, derived from a greater number of stations than the true AE indices, were used to generate a list of substorms that extended from 1998-2005. The initiation times of the substorm events were used to select the data for a spherical harmonic fit analysis, to produce a statistically averaged response of the ground-based perturbations in the Earth's magnetic field following the onset of substorms. Events were sorted by IMF orientation, season, and peak magnitude of the substorm AL index. Maps of the three vector components of the averaged magnetic perturbations for each IMF orientation are presented. The results shown indicate that factors from all three categories are quite significant, and explain 33-67% of the response, depending on the category. The seasonal influence was found to be much more significant than originally anticipated. These results could be used to supplement existing models of geomagnetic perturbations, in order to show the effects that could be expected from a substorm having specified values for the peak AL index and IMF orientation.
Systems Engineering and Communications

Session Chair: Arun Padakandla
To explore or to exploit
Yang Liu\textsuperscript{1}, Mingyan Liu\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

In this paper we consider an Opportunistic Spectrum Access (OSA) problem. For our problem, we consider the case with total $N$ i.i.d. Markovian channels. Each channel evolves as an i.i.d. two state discrete-time Markov chain. The two states are state 1 indicating a 'good' condition and state 0 indicating a 'bad' one. Also in our problem we consider a homogeneous network with state transition probability given by an uniform set of parameters $p_{ij}$, $i,j=0,1$ for all channels. At the end of each time slot, the user can pick $k$ out of $N$ channels to sense sequentially due to sensing capability and make a decision on which channel actually to transmit data on for the next time slot. For each successive transmission(transmit on certain channel with state 1), user will collect reward 1; otherwise user gets nothing(reward 0). The objective of the user is to maximize its throughput over finite time horizon $T$. The problem falls into POMDP category in general where the optimal sensing strategy is intractable. We investigate the property of the optimal sensing strategy and show under what conditions myopic sensing(greedy sensing policy) is guaranteed to be optimal; and on the other hand under what condition exploration by deviation from myopic sensing would bring in benefits.
Collective revelation through mechanism design
Parinaz Naghizadeh Ardabili\(^1\) and Mingyan Liu\(^1\)

\(^1\)Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

We address the following mechanism design problem: in a distributed multi-agent/entity system where entities possess observations or beliefs about one another, with the truth about an entity only known to itself, how to construct elicitation and aggregation mechanisms that can provide incentives for the agents to participate in the collective effort of arriving at the correct assessment of all participants without violating privacy and self-interest. We observe that when designing such mechanism, we need to tackle two main challenges: (1) the need to provide incentives to ensure voluntary participation, and (2) the possibility of untruthful input from the agents who choose to collaborate. Our main motivation is to establish, in a system of interconnected networks, the accurate assessment of different networks in terms of their security posture, through collective participation and crowd sourcing. Such quantitative assessment, referred to as the reputation of a network, represents the perceived risks a network poses in the system, and can be used to construct risk-aware policies that are proactive in nature. We propose a number of utility models to represent possible strategic behavior of the networks. For each model, we either construct the optimal mechanism leading to the socially optimal solution (achieving the solution to the centralized problem), or present incentive compatible sub-optimal solutions. Our main finding in the latter case is that even when incentivizing truthful input to implement the optimal solution is not feasible, using a simple punish-reward mechanism induces networks to provide useful input, improving the system performance.

The work is partially supported by the NSF under grant CIF-0910765 and the U.S. Department of Commerce, National Institute of Standards and Technology (NIST) Technology Innovation Program (TIP) under Cooperative Agreement Number 70NANB9H9008.
On the optimality of a myopic policy in multi-state channel probing

Yi Ouyang	extsuperscript{1}, Demosthenis Teneketzis	extsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

We consider the channel probing problem that arises in cognitive radio networks, in opportunistic scheduling over fading channels, and in resource-constrained jamming. The communication system under consideration consists of \( N \) channels. Each channel is modeled as a multi-state Markov chain (M.C.). At each time period a user selects one channel to probe and uses it to transmit information. A reward depending on the state of the selected channel is obtained for each transmission. The objective is to design a channel probing policy that maximizes the expected total reward collected over a finite or infinite horizon. The resulting optimization problem is a Partially Observed Markov Decision Process (POMDP); it is also an instance of a restless bandit problem, for which the form of optimal policies is unknown in general. We discover conditions sufficient to guarantee the optimality of a myopic probing policy.
An achievable rate region for the 3 user interference channel using algebraic codes
Arun Padakandla, Aria G. Sahebi, S. Sandeep Pradhan

Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Interference channel (IC) is a model for communication between multiple source destination pairs that share a common communication medium. Of fundamental importance is a computable characterization of it’s capacity region, i.e., the set of rates at which information can be simultaneously communicated from sources to their respective destinations. In this work, we focus on characterizing an achievable rate region, i.e., an inner bound to the capacity region, of a three user interference channel (3-IC). In a 3-IC the transmitted signal of each user is corrupted by a bivariate function of the signals transmitted by the other users. Therefore, it is of interest to design signals of each transmitter jointly such that the range of this bivariate function is contained. We propose the use of codes, such as nested coset codes and group codes, that possess algebraic properties which enable containing the set of all interference patterns. We propose novel encoding and decoding techniques that exploit these algebraic properties and thereby enable better interference management. This enables us derive a new achievable rate region for the 3-IC. We also identify examples for which the proposed achievable rate region is strictly larger than the Han-Kobayashi rate region which is the currently known largest rate region for the general 3-IC.

This work was funded, in part, by NSF Grants CCF-0915619 and CCF-1116021.
Polar codes for sources with finite reconstruction alphabet
Aria G. Sahebi, S. Sandeep Pradhan

Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Polar codes are a class of linear codes recently developed to achieve the symmetric capacity of binary discrete memoryless channels. These codes are constructed based on the Kronecker power of the two-by-two matrix $\begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$ and constitute the first known class of capacity achieving codes with an explicit construction. It was subsequently shown that polar codes employed with a successive cancelation encoder are also optimal for the lossy source coding problem when the size of the reconstruction alphabet is two. In an earlier work, we showed that polar codes can achieve the symmetric capacity of arbitrary discrete memoryless channels regardless of the size of the channel input alphabet. The encoding rule that we use for non-binary polar codes consists of two linear codes, one included in another, so that the cosets of the inner code in the outer code exhibit good coding properties. In this paper, we show that polar codes are also optimal for the source coding problem and achieve the symmetric rate-distortion bound when the size of the reconstruction alphabet is finite. We employ a modified randomized rounding encoding rule to achieve the symmetric rate-distortion bound. This construction of the polar codes is the first known construction of codes capable of achieving the symmetric rate-distortion bound for arbitrary finite sources. We use a combination of Algebraic, probabilistic and information-theoretic tools.

This work was funded, in part, by NSF grants CCF-0915619 and CCF-1116021.
Profit incentive in a secondary spectrum market: a contract design approach
Shang-Pin Sheng, Mingyan Liu

1Electrical Engineering and Computer Science, University of Michigan

In this paper we formulate a contract design problem where a primary license holder wishes to profit from its excess spectrum capacity by selling it to potential secondary users/buyers. It needs to determine how to optimally price the excess spectrum so as to maximize its profit, knowing that this excess capacity is stochastic in nature, does not come with exclusive access, and cannot provide deterministic service guarantees to a buyer. At the same time, buyers are of different types, characterized by different communication needs, tolerance for the channel uncertainty, and so on, all of which a buyer’s private information. The license holder must then try to design different contracts catered to different types of buyers in order to maximize its profit. We address this problem by adopting as a reference a traditional spectrum market where the buyer can purchase exclusive access with fixed/deterministic guarantees. We fully characterize the optimal solution in the cases where there is a single buyer type, and when multiple types of buyers share the same, known channel condition as a result of the primary user activity. In the most general case we construct an algorithm that generates a set of contracts in a computationally efficient manner, and show that this set is optimal when the buyer types satisfy a monotonicity condition.
Optimal power allocation for a renewable energy source

Abhinav Sinha\textsuperscript{1}, Prasanna Chaporkar\textsuperscript{2}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Electrical Engineering Department, Indian Institute of Technology, Bombay, India

Battery powered wireless transmitters face energy constraint, thus replenishing their energy by a renewable energy source (like solar or wind power) can lead to longer lifetimes. We consider here the problem of finding the optimal power allocation under random channel conditions for a wireless transmitter, such that rate of information transfer is maximized. Here a rechargeable battery, which is periodically charged by a renewable source, is used to power the transmitter. All of the above is formulated as a Markov Decision Process. Structural properties like the monotonicity of the optimal value and policy derived in this paper will be of vital importance in understanding the kind of algorithms and approximations needed in real-life scenarios. The effect of curse of dimensionality which is prevalent in Dynamic programming problems can thus be reduced. We show our results under the most general of assumptions and we also generalize the result to battery state dependent recharging scenario. This work has close application for sensors which are usually kept in inaccessible regions for measuring data.

\textit{This work was funded, in part, by IU-ATC.}
Online contract design with ordered preferences
Cem Tekin\textsuperscript{1}, Mingyan Liu\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

We consider a seller who offers a fixed number of contracts to buyers that arrive in a sequential manner. A buyer's type is drawn from a distribution which is unknown to the seller. The goal of the seller is to maximize its payoff by offering the best set of contracts to the buyers. If a contract from the offered set is accepted, the seller gets a payoff depending on the buyer's type and the accepted contract. If none of the offered contracts is accepted, the seller does not get any reward. Moreover, there is a cost associated with offering contracts so the seller cannot offer a large number of contracts. We consider buyer cost functions that induce ordered preferences. If buyer accepts contract $x$, then it will accept any contract $x' < x$, provided that $x'$ is offered alone.

Contract design problems have useful applications such as contract design in a secondary spectrum market for wireless communications and design of cellular plans for mobile service providers.

Since the buyer's type distribution is unknown a priori, we design online learning algorithms for the seller to maximize its total payoff over some time horizon $T$. Basically, at each time step, the seller offers a set of contracts, and based on the result of this offer updates its estimate about the distribution of the buyer's type. The seller should offer contracts to learn the distribution of buyer's type, while it should try to maximize its total payoff. Therefore, the seller faces an exploration-exploitation tradeoff. We show that sublinear regret can be achieved by an online learning algorithm. The time average performance of any algorithm with sublinear regret is equal to the average payoff from the optimal set of contracts given the distribution over the buyer's type.
On proving structural properties of optimal policies in control of queuing systems

Deepanshu Vasal, Achilleas Anastasopoulos

Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Control of dynamic systems like network queues is generally analyzed through framework of Markov decision processes (MDP) and the optimum cost is found as solution of resulting dynamic programming (DP) equation. But solving the DP equation is often not easy as the space of optimization can be huge. Thus one looks for more structural properties of the optimum cost function that are sufficient to prove 'simple' optimal policies for e.g. threshold policies. For a system of two queues, Hajek proved structural properties like convexity, superconvexity and supermodularity of cost function with controller having two possible control actions. His proof entails division of property into different cases and showing that property propagates through DP equation for each case. A similar analysis for more than two possible actions gets very complex to solve analytically. In this poster, we follow the formulation of Hajek and show that such problems can be represented as a problem of showing a polygon being contained in union of some polygons (which depend on the property to be proven) and thus can be solved computationally. This methodology can be used for queuing systems with more than 2 possible actions and to prove properties than can be represented as linear inequalities in state space.
When simplicity meets optimality: efficient transmission power control with stochastic energy harvesting
Qingsi Wang\textsuperscript{1} and Mingyan Liu\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

We consider the optimal transmission power control of a single wireless node with stochastic energy harvesting and an infinite/saturated queue with the objective of maximizing a certain reward function, e.g., the total data rate. We develop simple control policies that achieve near optimal performance in the finite-horizon case with finite energy storage. The same policies are shown to be asymptotically optimal in the infinite-horizon case for sufficiently large energy storage. Such policies are typically difficult to directly obtain using a Markov Decision Process (MDP) formulation or through a dynamic programming framework due to the computational complexity. We relate our results to those obtained in the unsaturated regime, and highlight a type of threshold-based policies that is universally optimal. We also investigate an alternative objective of completion time minimization for a given reward objective, and characterize its optimal solution with efficient online algorithms.
Enforcement of opacity properties using insertion functions
Yi-Chin Wu\textsuperscript{1}, Stéphane Lafortune\textsuperscript{1}

\textsuperscript{1}Department of EECS, University of Michigan, Ann Arbor, MI

Opacity is a confidentiality property that arises in the analysis of security properties in networked systems. It characterizes whether a “secret” of a system can be inferred by an outside observer called an “intruder.” We consider the problem of enforcing opacity in partially-observed discrete event systems modeled as automata. We propose a novel enforcement mechanism based on the use of insertion functions. An insertion function is a monitoring interface at the output of the system that changes the system’s output behavior by inserting additional observable events. The insertion function must respond to the full system’s output behavior. Also, the insertion function should not create new observed behavior but only replicate existing observable strings. We define the property of “i-enforceability,” when there exists an insertion function that renders a non-opaque system opaque. To synthesize insertion functions that ensure opacity, we define and construct a new structure called the “All Insertion Structure” (AIS). The AIS can be used to verify if a given opacity property is i-enforceable. The AIS enumerates all i-enforcing insertion functions in a compact state transition structure. If a given opacity property has been verified to be i-enforceable, we show how to use the AIS to synthesize an i-enforcing insertion function.

\textit{This work was funded, in part, by the U.S. National Science Foundation.}
Richard and Eleanor Towner Award for Outstanding Ph.D. Research Poster Competition
Significant power enhancement in photoconductive terahertz emitters by using plasmonic contact electrodes
Christopher W. Berry¹, Mona Jarrahi¹

¹Department of Electrical Engineering, University of Michigan, Ann Arbor, MI

Photoconductive emitters are one of the most commonly used sources of terahertz radiation. They consist of an ultrafast photoconductor connected to a terahertz antenna. Pulsed or heterodyning laser illumination of the photoconductor active area generates photocurrent with terahertz frequency components, which feed the antenna to generate terahertz radiation. Although the power efficiency of a photoconductive emitter can theoretically reach 100%, the inherent tradeoff between high quantum efficiency and ultrafast operation of conventional photoconductors has significantly limited the output power of photoconductive terahertz emitters. Here, we demonstrate that use of plasmonic contact electrodes can significantly enhance the optical-to-terahertz conversion efficiency in a photoconductive terahertz emitter. The use of plasmonic contact electrodes offers nanoscale carrier transport path lengths for the photocarriers, enabling efficient collection of the majority of carriers in a sub-picosecond time-scale. It also allows increasing photoconductor active area without a considerable increase in the capacitive loading to the antenna, boosting the maximum terahertz radiation power by preventing the carrier screening effect and thermal breakdown at high optical pump powers. We experimentally demonstrated 50 times higher terahertz radiation power from a plasmonic photoconductive emitter in comparison with a similar photoconductive emitter with non-plasmonic contact electrodes.

This work was funded, in part, by DARPA, NSF, ONR, and the Michigan Space Grant Consortium.
From molecular dynamics to statistical and complex network modeling of elastomer materials
Jacob Davidson and Nakhiah Goulbourne

Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

Recent advances in computing are rapidly changing polymer physics: It is now possible to directly observe and analyze microscopic phenomena previously impossible or prohibitively difficult to access via experiment. However, current engineering models of elastomers feature a gap in understanding with respect to the relation of microscopic quantities to macroscopic properties of interest. These relationships are especially important in the development and use of new materials (e.g. field-responsive polymers). We use multiscale modeling in combination with molecular dynamics simulations of elastomers in order to test basic assumptions in current engineering models of polymers and suggest methods for next-generation modeling. Multi-axial large deformation mechanical tests are simulated using a coarse-grained polymer model in order to mimic a typical engineering characterization of different elastomer materials. We use these results to construct a detailed picture of how the macroscopic deformation is transferred to individual chains. It is shown that although statistical averaging leads to a simple linear micro-macro deformation relationship, a similar relationship for stress does not exist. Beyond statistical modeling, we consider complex network theory as a tool to provide a more detailed picture of the randomly-disordered microscopic structure. Both chemical and physical crosslinks contribute to the network structure, and we demonstrate that this structure can be understood by considering a simple random network model with prescribed degree distribution. These results are used to identify multiscale deformation mechanisms in elastomers and suggest methods for modeling and development of new materials.
Advanced transmission electron microscopy studies of self-regenerative automotive catalysts
Michael B. Katz¹, George W. Graham¹, Xiaoqing Pan¹

¹Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

Catalysts are used to remove detrimental gases from the automobile exhaust stream, thus fulfilling an essential need in increasingly environmentally conscious times. The constituent functional materials – some combination of Pt, Pd, and Rh – that compose the catalyst nanoparticles are both rare and expensive, and their performance degrades throughout the catalytic converter lifetime via thermodynamically driven losses of the catalytically active surface area during prolonged exposure to high exhaust temperatures. Conventional oxide powder supports, used to stabilize the catalyst nanoparticles against migration and coarsening, retard coarsening to some degree, but coarsening is nonetheless irreversible on these supports. We report here on microscopy and density functional theory studies of a new class of self-regenerative catalyst/support systems, wherein the catalyst absorbs into a specially selected perovskite oxide support (e.g. LaFeO₃ for Pd; CaTiO₃ for Pt, Rh) and re-emerges as nanoparticles in a high dispersion. Utilizing ab initio modeling, we find that this behavior is the result of balanced thermodynamic equilibria in which the normal stoichiometric oscillations of the air-fuel mixture alternately favor the catalyst existing as a metallic phase and as a solid solution within the perovskite. Using ex-situ and in-situ transmission electron microscopy experiments on model thin films and powders to study the phenomenology, we find that the movement of catalyst atoms is slower than expected, however, and much of the metal may fail to reach the support surface upon regeneration. Therefore, the morphology of the catalyst support must be carefully engineered for the self-regenerative catalyst to be effective and practical.
Structural Metrics of Tuning Atomic Motions for Superior Thermoelectrics
Hyoungchul Kim and Massoud Kaviany

Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109

Atomistic displacement in thermoelectric (TE) allows for tuning their properties for superior figure-of-merit ($ZT$). Accurate atomic motion description is essential, since structural metrics derived from harmonic and quasi-harmonic approximations have several limits. This accurate prediction is now possible with advances in multiscale [$ab$-$initio$, molecular dynamics, Boltzmann (meso), and macro] treatments. Using these and chalcogenides, skutterudites, and icosahedral structures, we propose novel structural metrics for tuning atomic motions for high $ZT$. The maximum in $ZT$ for most materials is reached at temperatures representing optimal interactions between charge carriers and phonon. Our theoretical treatment demonstrates that for mid- and high-temperature range TE materials, significant thermal disorder and phonon-assisted softening cause this maximum in $ZT$. Thermal atomic disorder leads to band convergence, i.e., some band peaks/valleys disappear. Disorder also creates a pseudo-amorphous structure which reduces the short and long-range acoustic phonon transport. The phonon softening (i.e., phonon redshifting) caused by significant electron-phonon interaction, affects the phonon and electron transport also resulting in maximum $ZT$. Such electron-phonon coupling becomes more distinct as temperature increases, resulting in unusual TE properties at high temperatures. Our ultimate goal is establishing the metrics for thermal-atomic-displacement based superior TE materials.

*This work was funded by the Center for Solar and Thermal Energy Conversion at University of Michigan, an Energy Frontier Research Center funded by the US Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0000957.*
Parallel Algorithm for Whole-Core 3-D Neutron Transport Calculations using the Method of Characteristics
Brendan Kochunas\textsuperscript{1} and Prof. Tom Downar\textsuperscript{1}

\textsuperscript{1}Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI

The field of Light Water Reactor (LWR) analysis has recently made efforts to significantly advance their simulation capability made possible by state of the art petascale super computers. The principal economic motivation for improved reactor core calculations has been to increase reactor power density and operational flexibility without compromising reactor safety. Full core 3-D transport calculations make this possible by reducing the uncertainty of computed solutions and employing first principle based methods. In this work a new parallel algorithm for the solution of the Boltzmann transport equation by the Method of Characteristics (MOC) is developed, verified, and analyzed. The algorithm decomposes the neutron flux in the space, energy, and angle phase spaces; as well as along the discrete characteristic rays. The correctness of the method is verified using the Takeda 3-D Transport Numerical Benchmark. Results compared to within 40 pcm of the reference which had a statistical uncertainty of 60 pcm. An initial study on the computational performance was also done to assess the parallel efficiency of the algorithm. The overall observed strong scaling efficiency of the algorithm is estimated at 52\%. Suggested improvements to the parallel decomposition are presented and demonstrated to increase this efficiency to approximately 90\%. It is concluded that the algorithm is correct and can be made very efficient. Future work will focus on improving overall performance and continued validation.

\textit{This work was funded by the Consortium for Advanced Simulation of Light Water Reactors (CASL), an Energy Innovation Hub for Modeling and Simulation of Nuclear Reactors under the U.S. Department of Energy Contract.}
Respec: Efficient online multiprocessor replay via speculation and external determinism
Dongyoon Lee, Benjamin Wester, Kaushik Veeraraghavan, Satish Narayanasamy, Peter M. Chen, Jason Flinn.

Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Parallel programming is inherent complex due to non-determinism that a given input is not guaranteed to produce the same output across different executions. Therefore, it is critical that we produce software tools that can drastically simplify parallel programming. A deterministic replay system can serve as a foundation for building many useful tools by overcoming the inherent non-determinism in multiprocessor systems. In the recent past, VMware, Microsoft and Intel have all realized this need and have produced deterministic replay tools such as ReTrace, iDNA and pinPlay. While it is well known how to replay uniprocessor systems, replaying shared memory multiprocessor systems at low overhead on commodity hardware is still an open problem. This work presents Respec, a new way to support deterministic replay of shared memory multithreaded programs on commodity multiprocessor hardware. Respec targets online replay in which the recorded and replayed processes execute concurrently. Respec uses two strategies to reduce overhead while still ensuring correctness: speculative logging and externally deterministic replay. Speculative logging optimistically logs less information about shared memory dependencies than is needed to guarantee deterministic replay, then recovers and retries if the replayed process diverges from the recorded process. Externally deterministic replay relaxes the degree to which the two executions must match by requiring only their system output and final program states match. We show that the combination of these two techniques results in about 18% overhead to the execution time for recording and replaying programs with two threads and 55% overhead for programs with four threads.

This work was funded, in part, by the National Science Foundation award CNS-0905149. Peter Chen is supported by NSF award CNS-0614985 and Intel Corporation. Jason Flinn is supported by NSF CAREER award CNS-0346686. Satish Narayanasamy is supported by NSF award CCF-0916770 and Microsoft.
Algae cannibalism: using hydrothermal carbonization to recycle nutrients in algal biofuel production
Robert Levine\textsuperscript{1}, Christian Sambolin\textsuperscript{2}, Phillip E. Savage\textsuperscript{1}

\textsuperscript{1}Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Chemical Engineering, University of Puerto Rico at Mayagüez, Mayagüez, Puerto Rico

Worldwide demand for liquid transportation fuels and growing concern about the impacts of our continued reliance on petroleum have encouraged the use of plant-based fuels. Recently, interest has grown in using oleaginous microalgae as a non-edible biofuel feedstock, largely on the promise of high oil yields, the opportunity to capture waste CO\textsubscript{2}, and the ability to cultivate algae on currently unproductive land using brackish, salt, or wastewaters instead of freshwater. However, the production of algal biofuels is complicated by their high demand for nitrogen and phosphorus fertilizers. In this work, we explore a new and environmentally preferable strategy for producing transportation fuels from algae called hydrothermal carbonization (HTC).

During HTC, algae biomass is reacted in high temperature water (180-210 °C) at autogenous pressures to produce a biochar and nutrient-rich aqueous phase. The solid biochar contains most of the oils originally present in the biomass and is further processed to produce biodiesel. The aqueous phase generated from HTC typically contains about half of the nitrogen and a majority of phosphorous present in the biomass and is recycled to the algae growth reactors. We have demonstrated that both a freshwater and saltwater algae are capable of growing on the dissolved nitrogen, phosphorus, and carbon within the aqueous phase, thereby reducing the need for external fertilizers in the biofuel production process and helping make algal biofuels a more sustainable alternative to petroleum.

This work was funded, in part, by NSF Grant CBET-1133439.
Anthropogenic emissions enhance the biogenic SOA formation and its radiative cooling effect
Guangxing Lin\textsuperscript{1} and Joyce E. Penner\textsuperscript{1}

\textsuperscript{1}Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, Ann Arbor, Michigan, USA.

Organic aerosols play an important role in climate change through their radiative forcing. Here, we use a fully explicit secondary organic aerosol (SOA) formation model to investigate the change in SOA between present day and pre-industrial conditions and to assess the radiative forcing associated with SOA. Anthropogenic emissions of NO\textsubscript{x}, CO, sulfate, biomass burning and fossil fuel organic aerosol are shown to influence the formation rate of biogenic SOA substantially, causing it to increase by 18.6 Tg/yr (23.3\%) since pre-industrial times. The increase of SOA results in a global direct forcing ranging from 0.06 to 0.21 Wm\textsuperscript{-2} and a global first indirect forcing ranging from -0.24 to -0.32 Wm\textsuperscript{-2}, with the range due to different assumed size distributions for SOA and different refractive indices. The uncertainties associated with the estimate of radiative forcing from this model are also discussed.
Moving target detection and tracking with hierarchical Bayesian models in synthetic aperture radar imagery

Gregory Newstadt\textsuperscript{1}, Edmund G. Zelnio\textsuperscript{2}, Alfred O. Hero, III\textsuperscript{1}

\textsuperscript{1}Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433.

In synthetic aperture radar (SAR), images are formed by focusing the response of stationary objects to a single spatial location. On the other hand, moving targets cause phase errors in the standard formation of SAR images that cause displacement and defocusing effects. SAR imagery also contains significant sources of non-stationary spatially-varying noises, including antenna gain discrepancies, angular scintillation (glints) and complex speckle. In order to account for this intricate phenomenology, this work combines the knowledge of the physical, kinematic, and statistical properties of SAR imaging into a single unified Bayesian structure that simultaneously (a) estimates the nuisance parameters such as clutter distributions and antenna miscalibrations and (b) estimates the target signature required for detection/inference of the target state. Moreover, we provide a Monte Carlo estimate of the posterior distribution for the target state and nuisance parameters that infers the parameters of the model directly from the data, leading to little tuning of algorithm parameters. We demonstrate that our algorithm competes at least as well as state-of-the-art algorithms for optical imaging on a synthetic dataset. Moreover, performance analysis on measured SAR imagery shows that the proposed algorithm is robust at detecting/estimating targets over a large scene and performs at least as well as popular algorithms for SAR moving target detection.

This work was funded, in part, by Air Force Office of Scientific Research award FA9550-06-1-0324 and by Air Force Research Laboratory award FA8650-07-D-1221-TO1.
Advanced concrete development for resilient and sustainable infrastructure

Ravi Ranade

Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI

Modernizing civil infrastructure has been identified as one of the grand challenges of the 21st century by the National Academy of Engineers as resilience and sustainability of infrastructure are called into question. The American Society of Civil Engineers (ASCE) in its “Report Card for America’s Infrastructure” (2011) has identified critical deficiencies in resilience and sustainability of the US infrastructure. One of the main underlying problems responsible for the limited performance of infrastructure is the construction material – concrete. The brittleness of concrete not only poses the risk of catastrophic structural collapse under severe loading such as earthquakes, hurricanes, or bomb blasts, but also leads to cracks with large openings under service loads allowing ingress of corroding agents which accelerate the structural deterioration. Cement and other ingredients of concrete with high environmental footprint make its production unsustainable in the future. The objective of this research is to develop a new concrete for infrastructure resilience and sustainability. At the material scale, this necessitates the integration of strength, ductility (low brittleness), durability, and environmental greenness in one concrete. While each of these properties has been individually infused in concrete in the past, their integration has not been possible due to starkly contrasting design philosophies and tradeoffs. Through the application of micromechanics, multi-scale modeling, and life cycle analysis techniques, this doctoral research aims at achieving such concrete material to meet the grand challenge of 21st century infrastructure modernization in harmony with the natural environment.

This work was funded, in part, by US Army Engineer Research and Development Center (ERDC), Vicksburg, MS.
Dual-phase engineered tissue for enhanced bone regeneration
Rameshwar R. Rao\textsuperscript{1} and Jan P. Stegemann\textsuperscript{1}

\textsuperscript{1}Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

This project applies an innovative approach to the healing of bone fractures, which account for over $26 billion in healthcare costs. “Non-unions” are broken bones that fail to heal due to the lack of proper blood supply into the defect site. In our approach, we create modular engineered tissues designed to form bone and combine them with a surrounding vascularizing tissue, to create a dual-phase injectable matrix for enhanced bone regeneration. In the first Aim, human bone marrow mesenchymal stem cells (MSC) or human adipose stem cells (ASC) were embedded in collagen/fibrin (COL/FIB) or collagen/fibrin/hydroxyapatite (COL/FIB/HA), and their osteogenic potential was compared. Both cell types mineralized the microbeads, indicating both MSC and ASC differentiated towards the osteogenic lineage. The second Aim used a co-culture model of MSC and human endothelial cells (EC) in COL/FIB composite hydrogels to create a vasculogenic matrix upon implantation. Cell ratio and matrix composition were varied in a systemic manner. Network formation increased with increasing fibrin content in composite materials, although the 40/60 COL/FIB and pure fibrin materials exhibited the same degree of vasculogenesis. The vasculogenic potential of these COL/FIB hydrogels was then evaluated \textit{in vivo}. After 7 days, explanted tissues exhibited neovascularization. In the final Aim, osteogenic microbeads will be distributed within a vasculogenic matrix to demonstrate enhanced bone formation \textit{in vitro} and \textit{in vivo}. The goal of this work is to create well-vascularized engineered bone tissue for transplantation, which will have a significant impact on the treatment of non-unions and other recalcitrant bone injuries.

\textit{This work was funded, in part, by the National Science Foundation Graduate Research Fellowship, Grant No. DGE 1256260.}
Photoconductivity in organic photovoltaics
C. K. Renshaw¹, J. D. Zimmerman², B. E. Lassiter³, and S. R. Forrest¹,²,³

¹Department of Physics, University of Michigan, Ann Arbor, MI
²Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI
³Department of Materials Science and Engineering, University of MI, Ann Arbor, MI

Organic photovoltaics (OPVs) differ from ideal inorganic solar cells in their pronounced voltage dependence of the photocurrent ($J_{ph}$) under reverse bias. When linear, this feature is commonly modeled in an ad hoc fashion by including a parallel junction resistance ($R_p$) and this voltage dependence is commonly attributed to the electric field dependence of the dissociation of polaron pairs (PP) that are bound at the heterojunction. We show this behavior can also arise from photoconductivity within the bulk of the donor and acceptor layers. Photoconductivity can mask the field dependence of PP dissociation affecting the analysis and optimization of device performance. Ultimately, the presence of photoconductivity does not result in an increase in power conversion efficiency, and places a constraint on the maximum fill factor that can be achieved in an OPV cell.

This work was funded, in part, by the Center for Solar and Thermal Energy Conversion at UM (DOE-EFRC: CSTEC), the NSF SOLAR program and collaborative R&D program with the Ministry of Knowledge and Economy of Korea.
Picowatt-resolution heat flow calorimetry
Seid Sadat$^1$, Edgar Meyhofer$^1$, Pramod Reddy$^{1,2}$.

$^1$Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI
$^2$Department of Material Science, University of Michigan, Ann Arbor, MI

We demonstrate a microfabricated heat flow calorimeter capable of measuring modulated heat currents with ~5 pW resolution. This is accomplished by integrating a platinum (Pt) resistance thermometer into a suspended microdevice that is thermally isolated (thermal conductance ~150 nW/K) by thin and long beams. The high-resolution thermometry is achieved by employing a matching resistance to reject the ambient temperature fluctuations and adopting a thermometry scheme where an unmodulated sensing current is used to detect modulated temperature changes. The demonstrated resolution is comparable to that of state-of-the-art devices (Sadat et al., APL, 2011) with integrated bimaterial cantilevers (~4 pW), while dissipating an order of magnitude lower power in the measurement process. The enhanced heat-flow calorimetric resolution demonstrated here will enable fundamental studies of phonon transport at the molecular scale and near-field radiative heat transfer in nanoscale gaps.

*This work was funded, in part, by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-SC0004871.*

Amir Sadrpour\textsuperscript{1}, Judy Jin\textsuperscript{2}, A.G. Ulsoy\textsuperscript{3}.

\textsuperscript{1}Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{2}Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI
\textsuperscript{3}Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

A typical unmanned ground vehicle (UGV) mission can be composed of various tasks and several alternative paths. Small UGVs commonly rely on electric rechargeable batteries for their operations. Since each battery has limited energy storage capacity, it is essential to predict the expected mission energy requirement during the mission execution and update this prediction adaptively via real-time performance measurements, such as the vehicle power consumption and velocity. We proposed and compared two methods in the paper. One is based on recursive least squares estimation (RLSE) built upon the UGV longitudinal dynamics model alone. The other is based on Bayesian estimation when prior knowledge, e.g., road average grade and operator driving style, is available. In this case, the proposed Bayesian prediction can effectively combine the prior knowledge with real-time performance measurements for adaptively updating the prediction of the mission energy requirement. Our comparative experimental and simulation studies show that the Bayesian model can yield more accurate predictions compared to the linear regression model even with moderately imprecise mission prior knowledge.

\textit{This research was supported in part by the Ground Robotics Reliability Center (GRRC) at the University of Michigan, with funding from government contract DoD-DoA W56H2V-04-2-0001 through the United States Army Tank Automotive Research, Development and Engineering Center (TARDEC).}
Synthesis and Self-Assembly of Amphiphilic Janus Particles
Jaewon Yoon¹, Arun Kota², Anish Tuteja¹,², Joerg Lahann¹,²,³,⁴

¹Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, MI
²Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI
³Department of Chemical Engineering, University of Michigan, Ann Arbor, MI
⁴Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

Amphiphilic Janus particles are composed of both hydrophilic and hydrophobic regions. The synthesis and applications of amphiphilic Janus particles, including stabilization of emulsions, were studied for the past several years. Previously, we have developed electrohydrodynamic (EHD) co-jetting to fabricate multicompartmental anisotropic particles with different functionality in each compartment. Here, we report a new strategy to produce amphiphilic Janus particles via EHD co-jetting. In this technique, selective encapsulation of hydrophobic fluorodecyl-polyhedral oligomeric silsesquioxane (F-POSS) in one hemisphere and selective hydrolysis of poly(vinyl acetate) (PVAc) in the other hemisphere results in amphiphilic Janus particles. We have investigated the behavior of the amphiphilic Janus particles at an oil-water interface. The surfactant-like amphiphilicity allows strong adsorption of these particles at the interface. The combination of such amphiphilicity and nanoscale particle size is an important prerequisite for particulate surfactants to effectively stabilize emulsions.