EGS ENGINEERING GRADUATE SYMPOSIUM

UNIVERSITY OF MICHIGAN

# Abstract Booklet

## 13th Annual Engineering Graduate Symposium

Friday, October 26th, 2018

College of Engineering, University of Michigan, Ann Arbor

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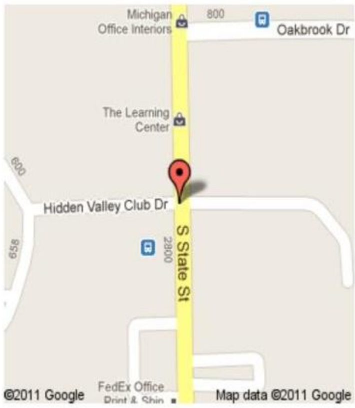


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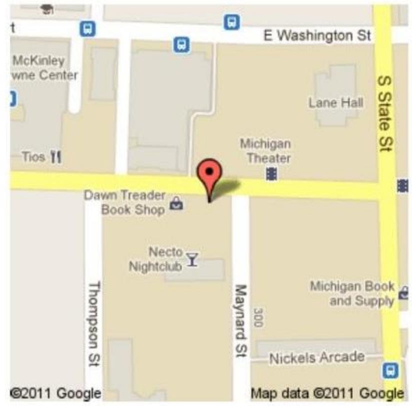


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Orlando Trejo

Rachel Young*

Wenlin Zhang

Hong Zhou*

Yuqing Zhou*

Yakun Zhu

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# Richard and Eleanor Towner Prize for Outstanding Ph.D. Research Oral and Poster Competition (TOWNER)

# Morning Session:
# 9:45 am – 12:00 pm
# Duderstadt Gallery

# Towner Morning Session Nominees

| Department | Name | Advisor |
|---|---|---|
| AERO | Sarah Cusson | Alec Gallimore and Benjamin Jorns |
| BME | Olivia Palmer | Joan Greve |
| ChE | William Kelley | Lola Eniola-Adefeso |
| CEE | Houtan Jebelli | SangHyun Lee |
| CLASP | Matthew Wozniak | Allison Steiner |
| CLASP | Tianlin Wang | Chris Ruf |
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| Robotics | Katherine Skinner | Matthew Johnson-Roberson |

# Towner Morning Session Abstracts

## Acceleration Region Movements in a Magnetically Shielded Hall Thruster (TOWNER_1)


### Sarah E. Cusson, Ethan T. Dale, Benjamin A. Jorns, Alec D. Gallimore

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



Hall effect thrusters use a crossed magnetic and electric field to ionize and accelerate propellant. They currently have decades of flight history on orbit. Yet, these devices still have some fundamental open questions about their operation. One major ambiguity of critical importance is the difference between operation of these device in ground test facilities versus on-orbit. This leaves an open question as to whether ground testing results translate to flight. These thrusters are known to operate differently in the two settings. This discrepancy is thought to be a result of non-vanishing background pressure and the presence of a grounded boundary changing the properties of the plasma discharge. These so-called "facility effects" have been widely characterized experimentally with most thruster configurations showing susceptibility to at least the effect of background pressure variation.

The major challenge with understanding these effects is that they appear to be non-classical. In particular, the accelerating mechanism for the ions in the thruster is known to vary. Here, the influence of the cathode flow fraction and facility background pressure on this acceleration region of a Hall thruster is experimentally characterized. The location of the acceleration region is measured using laser induced fluorescence on the H9 Hall thruster for six different facility background pressures and four different cathode flow fractions. Results show that when the facility pressure is increased from 7.1 × 10-6 to 3.0 × 10-5 Torr-Xe, the acceleration region shifts inward 1.6 ± 0.5 mm. Similarly, when the cathode flow fraction is increased from 7% to 15%, the acceleration region shifts inward 0.9 ± 0.5 mm. This experiment leads to two conclusions. First, introducing neutral in the cathode region can directly affect the accelerating mechanism in the thruster. Second, changing the cathode flow fraction affects the channel of the thruster in a similar manner as the background pressure. This similarity may be explained by local changes in the neutral density. Estimations of this parameter shows that the increase in neutral density in the proximity of the acceleration region is similar due to both effects. This provides correlational evidence linking the role of neutral density to the acceleration region shift in Hall thrusters. The results are also discussed in the context on impact on high power thrusters.

# Non-Invasive Determination of Thrombus Composition: Towards Patient-Specific Treatment Planning for Deep Vein Thrombosis (TOWNER_4)


## Olivia R. Palmer[1], Jose A. Diaz[2], Joan M. Greve[1]

[1]*Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI*

[2]*Department of Vascular Surgery, University of Michigan, Ann Arbor, MI*


Deep vein thrombosis (DVT) is known as the silent killer—there may be few or no symptoms, yet a section of the thrombus could break free and travel to the lungs, causing a pulmonary embolism. DVT and its sequelae affect 900,000 people in the U.S. each year, with one third of cases resulting in fatality. Anticoagulants (the standard treatment) pose bleeding risks and are not effective at preventing post thrombotic syndrome or recurrence. Thus, removing the DVT completely via lysis therapies is preferred. One such therapy, catheter directed thrombolysis, is only effective on acute thrombi, but determining the age of the thrombus by a timeline of symptoms alone is unreliable and can put the patient at risk. Our objective is to develop a magnetic resonance imaging (MRI) framework for determining thrombus composition.

We used murine models of DVT to test the hypothesis that thrombus composition varies spatially and temporally, and that composition can be determined non-invasively using non- contrast MRI. T1-, T2- and T2*-weighted MRI sequences were optimized for multispectral thrombus imaging on a small animal 7 Tesla MRI system. Mice were imaged at days 2, 6, and 14 following thrombus induction, then harvested for histology. A Gaussian mixture model was used for probabilistic clustering of the MRI signals. The resulting tissue map was compared with histology (Figure 1) to determine which signal signatures matched with known tissue composition as determined by histology.

Thrombus composition developed under blood stasis showed a bulls-eye pattern composition, whereas thrombus developed under blood flow conditions showed distinct composition differences between the head and tail of the thrombus. A correlation was observed between the GMM tissue map and corresponding histology. The green tissue class corresponds to unorganized thrombus, rich in platelets and red blood cells and is most prevalent at day 2 (17±2% day 2 vs. 7±1% day 14, $p<0.01$). Regions classified with the blue tissue class mirrored fibrin-rich regions, most prevalent at day 6 (75±2% day 6 vs. 47±5% day 2, $p<0.0001$, and 58±5% day 14, $p<0.05$). Similarly, the red tissue classification corresponds to tightly packed red blood cells at day 2. These cells release iron as they die, suppressing this signal at day 6 before they are replaced by monocytes which are most abundant at day 14 (minimum at day 6 with 12±2% vs. 37±4% day 2, $p<0.001$ and 31±5% day 14, $p<.01$). In conclusion, the GMM framework results provide a novel approach to study thrombus composition. This approach could eventually be used clinically to provide patient-specific treatment planning for DVT.

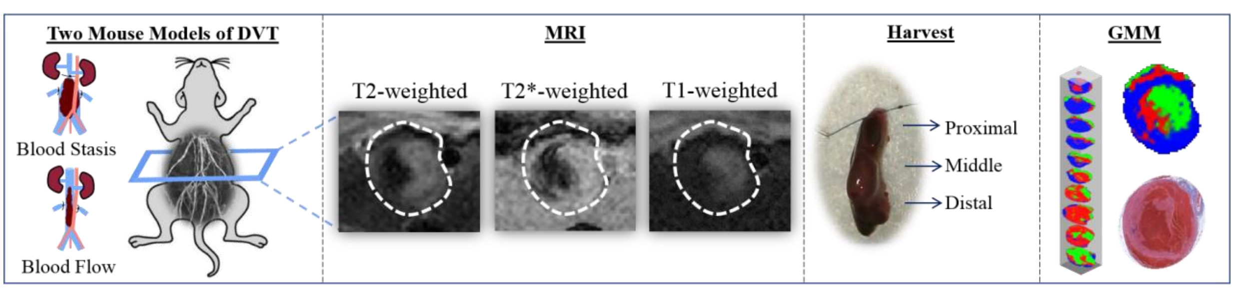


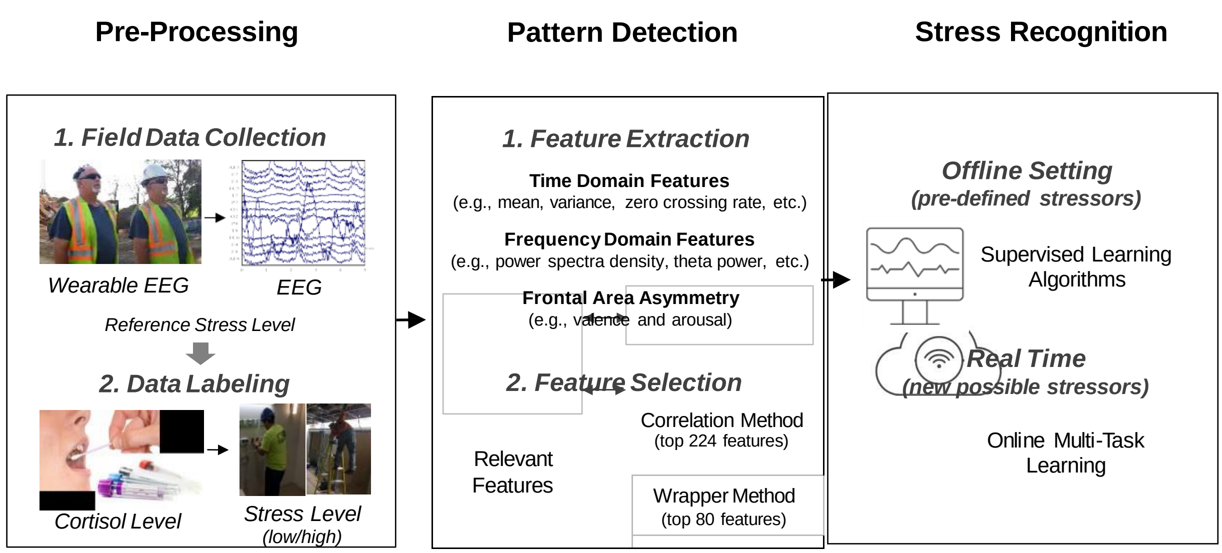

**Figure 1.** Schematic representation of experimental design. Thrombosis was induced using 2 common mouse models. Mice were imaged at days 2, 6, or 14 following DVT induction by 7 Tesla MRI, then immediately harvested for histology. A Gaussian mixture model (GMM) was used to classify the tissue and paired with histology.

# Mobile EEG-based Field Construction Workers' Stress Measurement (TOWNER_5)


## Houtan Jebelli, SangHyun Lee

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


Construction is one of the most stressful occupations due to its physically and psychologically demanding tasks performed in a hazardous work environment. Because workers' stress is a critical factor that adversely affects workers' productivity, safety, and well-being, an understanding of workers' stress should take precedence for the management of excessive stress. Various instruments for subjective measurement towards one's perceived stress have been used, but they rely on imprecise memory and reconstruction of feelings in the past, which limits their use in the field. Recent advancements in a wearable Electroencephalography (EEG) device possess a potential for continued measurement of human stress without interfering with workers' ongoing work. However, its capability of measuring field workers' stress under real occupational stressors remains challenging due to its significant noises and absurd signals when it is applied to field workers. To address these issues, we propose a comprehensive and efficient stress measurement framework by; 1) acquiring high-quality EEG signals via advanced signal processing techniques to remove prevalent artifacts at a job site; 2) automatically recognizing construction workers' stress in the field based on workers' brain activities by supervised learning algorithms (e.g., Support Vector Machine (SVM)); and 3) recognizing real-time stress by applying Online Multi-Task Learning (OMTL) algorithm. Results yielded a high of 80.13 % accuracy applying Gaussian Kernel SVM. In case of real-time stress recognition, our framework achieves 77.61% in recognizing workers' stress with OMTL. These results are very promising given that stress recognition with an exquisite and wired EEG device in the clinical domain has at most the similar level of accuracy. This EEG based stress detection approach is expected to better understand workplace stressors and to improve workers' productivity, safety, and well-being by early detection and mitigation of the factors that cause stress.



# Neutrophil Function in Health and Disease (TOWNER_7)


## William J. Kelley, Omolola Eniola-Adefeso

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


Although neutrophils account for approximately 60% of circulating leukocytes in humans, and are therefore the first line of defense against invading pathogens. However, neutrophil function in many contexts is relatively less well-understood compared to other leukocyte subsets due to the lack of reliable cell lines that approximate neutrophil behavior and the difficulty in performing complex experiments with primary neutrophils *ex vivo*. In this work, we aim to broaden the knowledge base of neutrophil behavior; specifically, how neutrophils interact with particulate drug carriers for inflammatory diseases and contribute to complications in a chronic inflammatory disease, antiphospholipid syndrome (APS). This work is novel in that our access to human blood donors allows us to examine primary neutrophil behavior in whole blood and plasma, and our unique expertise in blood flow dynamics can be used to understand how drug carriers and neutrophils interact in blood, as well as how neutrophils behave in a diseased state.

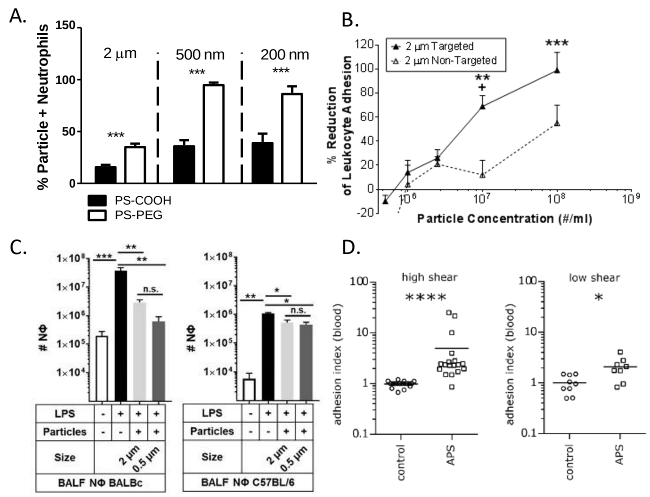



Figure 1-(A) Neutrophil phagocytosis of PEGylated particle drug carriers. (B) Inhibition of leukocyte adhesion by targeted and untargeted drug carriers. (C) Knockdown of neutrophil infiltration in inflamed lung tissue by administration of particle injections. (D) Increased adhesion of APS patient-derived neutrophils *in vitro*.

In this work, we find that polyethylene glycol (PEG) coatings meant to protect particle drug carriers from protein adsorption (and thus phagocytic clearance by leukocytes) actually promote phagocytosis by human neutrophils, and that this effect seems to be the result of interactions between PEGylated particles and complement proteins in human plasma—notably, we report for the first time a major difference between phagocytic behavior between animal and human cells linked to unique factors in human plasma. Further, we find for the first time that physical interactions between particle drug carriers and neutrophils in blood flow can interfere with the ability of neutrophils to bind to an inflamed endothelium, and that targeted drug carriers can specifically inhibit neutrophil adhesion. We also observe that particle phagocytosis by neutrophils can divert neutrophil adhesion and transmigration in an acute model of inflammation *in vivo*, with implications for researchers intending to design particle drug carriers to treat inflammatory diseases. Finally, we use a combination of flow cytometry and *in vitro* flow chamber experiments to observe neutrophil behavior in APS patients, finding that APS patient-derived neutrophils adhere significantly more to a quiet endothelium than control neutrophils, and that this effect is linked to an increased expression of MAC-1; these results suggest that a basal activation of APS patient neutrophils could play a role in inflammatory complications for APS patients.

Together, these results shed new light on the behavior of neutrophils, particularly how they interact with particle drug carriers and how they behave in inflammation. These results provide a framework for future researchers to dig deeper into neutrophil function, and how we might better design targeted therapies for inflammatory diseases involving neutrophils.

## Pollen in the Atmosphere: Modeling Emissions, Role in Clouds and the Impacts of Climate Change (TOWNER_9)


### Matthew Wozniak

*Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI*



Pollen is not just the reproductive medium of the majority of temperate flora, but behaves as an important aerosol in the Earth's climate system. From a pollen allergy perspective, predictability of pollen grains' emission and atmospheric dispersal is crucial to solving modern problems in allergy treatment and prevention. From an atmospheric scientist's perspective, the atmospheric environment will influence how pollen is emitted and dispersed but also pollen could bear influence on atmospheric processes like clouds and precipitation. How does climate determine the timing and amount of regional-scale pollen emissions, and how might airborne pollen influence its own climate? Moreover, as the climate changes, how will the emissions and distribution of airborne pollen be altered? Each of these questions is answered in three successive phases of my research that complete a story about pollen in the atmosphere. It starts with the development and evaluation of a novel, climate-sensitive pollen emission model (Pollen Emissions for Climate Models, or PECM) that enables the study of pollen on regional scales. We find that prior-year annual-average temperature drives emission phenology, or timing, and that a Gaussian-shaped timeseries model of pollen emissions parameterized by the phenological dates reproduces observed pollen counts when coupled with a regional climate model. Second, we develop a simulation of pollen rupture and release of subpollen particles (SPPs) in the regional climate model and their behavior as cloud condensation nuclei to study the effect of airborne pollen on clouds and precipitation. Our results show that SPPs have the potential to suppress precipitation on regional scales over the United States by up to 32%, implying that pollen could be consequential in the Earth's climate. Lastly, we use PECM to make projections of future pollen emission timing and distributions in the United States, producing a comprehensive dataset of climate change impacts on the pollen season for multiple airborne pollen taxa.

# Characterization of Effective Isotropic Radiated Power (EIRP) of the GPS Constellation for the CYGNSS Mission (TOWNER_10)


**Tianlin Wang[1,2], Christopher Ruf[1,2], Bruce Block[3], Darren McKague[1]**

*[1]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI [2]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI [3]Space Physics Research Laboratory, University of Michigan, Ann Arbor, MI*

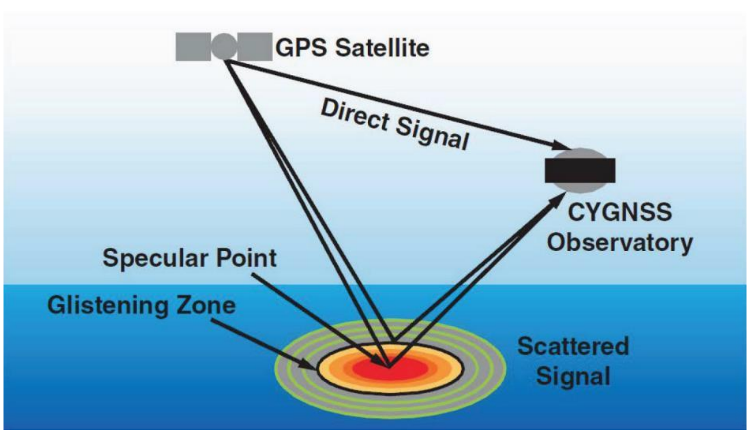

The Cyclone Global Navigation Satellite System (CYGNSS) uses a bistatic radar configuration with the Global Positioning System (GPS) constellation as the active sources and the CYGNSS satellites as the passive receivers. The GPS effective isotropic radiated power (EIRP), defined as the product of transmit power and antenna gain pattern, determines the directional radio frequency power incident on the Earth surface. EIRP is of great importance to the Level 1B calibration of the normalized bistatic radar cross section (NBRCS) of CYGNSS.

To address the uncertainties in EIRP, a ground-based GPS constellation power monitor (GCPM) system has been designed, built, calibrated, and operated to accurately and precisely measure the direct GPS signals. The calibration subsystem and low noise amplifier (LNA) are implemented on a proportional–integral–derivative (PID) controlled thermal plate with extremely stable temperature over the long term. The calibrated GCPM received power is highly repeatable and has been verified with DLR/GSOC's independent measurements.

The transmit power of the GPS constellation is estimated using an optimal search algorithm. Updated values for transmit power have been successfully applied to CYGNSS L1B calibration and found to significantly reduce the PRN dependence of CYGNSS L1 NBRCS and L2 data products, including the ocean surface wind speed and mean square slope (MSS).

The full GPS antenna patterns (over their terrestrial service volume) are estimated using the measurements made with the CYGNSS zenith antennas. They are demonstrated to be able to sample the full pattern within a very short time. An absolute power calibration is performed using the CYGNSS GPS signal simulator (GSS) and Delay-Doppler Mapping Receiver (DMR). By incorporating the zenith antenna measurements, the uncertainty in GPS EIRP due to transmitter antenna pattern asymmetry can be significantly reduced. The CYGNSS zenith antenna and receiver as a real-time GPS power monitor are also a powerful tool to capture any abrupt change in the GPS EIRP that may occur.

The system design and absolute power calibration scheme of the GCPM are helpful to the future design and implementation of GNSS receiver systems. The calibrated GPS transmit power and full transmit antenna pattern will be useful to the system design, science investigation and engineering calibration of future GNSS reflectometry missions.



# Heterogeneous Memory Subsystem for Natural Graph Analytics (TOWNER_11)


## Abraham Addisie, Hiwot Kassa, Opeoluwa Matthews, Valeria Bertacco

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


Graph applications are becoming essential in producing valuable insights from large amount of data that could be generated from social networks, internet of things systems, etc. Graphs are data structures where a set of vertices are connected by edges, and they are the primary framework to capture complex relationships in vast amounts of data. For instance, the Google search engine offers high-quality search results by analyzing cross-references in the network of web pages, medical centers diagnose brain diseases by examining functional brain connectivity from MRI data, and online maps generate efficient travel paths by analyzing road networks. For many of these applications, the data footprint is growing at a fast pace, as more individuals, businesses and embedded system devices (e.g.: web cams, vehicles, thermostats, etc.) increase their online presence. For others, our increasing sensing and processing accuracy leads also to larger datasets (e.g.: brain connectivity). As a result of this trend, the computational demands of graph-based applications have outgrown the computing abilities of traditional servers, which are built on chip multiprocessors (CMP). Hence, to deliver on the demands of emerging graph applications, there is a sharp need for new high-performance hardware architectures, specific for the graph processing domain.

In this context, we identified the memory subsystem in traditional chip multiprocessors to be the primary cause of performance inefficiencies, due to the large amount of data movement entailed by accessing the various components of a graph during the application's execution. However, we saw an opportunity in exploiting the locality aspects of many graphs, called "natural graphs", which occur frequently in practical situations. Indeed, many graphs derived from web connectivity, social networks, even biological networks, follow the power-law distribution, that is, 20% of the vertices are responsible for 80% of the accesses. Based on this observation, we propose a novel memory subsystem architecture tuned for these structures. Our solution, called OMEGA, leverages a mix of scratchpad storage, conventional cache memory, and specialized micro-units to process graph updates. We found experimentally that OMEGA provides 2.8x speedup, on average, over a CMP server running a state-of-art graph applications, it uses 2.5x less energy, and entails no silicon area overhead.

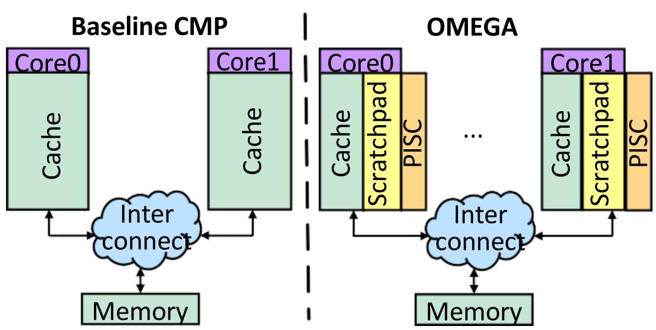



Figure 1(a). OMEGA provides a novel memory architecture to support graph-based computation in CMPs. It is implemented by replacing a portion of each core's cache with a scratchpad memory, organized to store the most-connected vertices, and augmented with a simple micro-processing unit (PISC) to carry out simple vertex computations in-situ.

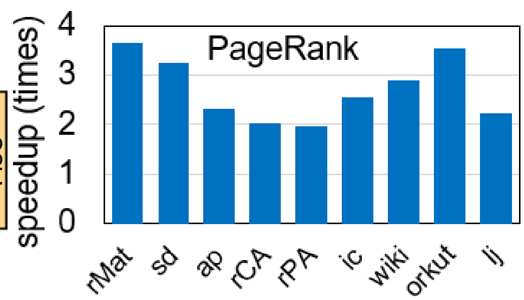



Figure 1(b). OMEGA offers a 2.8x speedup, on average, over a same-sized baseline CMP running the PageRank algorithm on a range of real-world graph datasets. Other algorithms tested show speedup ranging from 1.2x to 2.8x.

# Full Wave Simulations of Vegetation and Forest Effects in Microwave Remote Sensing of Soil Moisture (TOWNER_13)


## Huanting Huang, Leung Tsang

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


A large fraction of the soil is covered by vegetation/forests. Thus, understanding the effects of vegetation/forests on microwaves is important for active and passive remote sensing of soil moisture: in particular, how much electromagnetic energy can penetrate through the vegetation/forests to reach the soil underneath. Two commonly used microwave models are the distorted Born approximation (DBA) and the radiative transfer equation (RTE). In RTE and DBA, the transmission through vegetation/forests is calculated as $t = exp(-\kappa_e d sec(\theta i))$, where $\kappa_e$ is the attenuation rate per unit distance, $d$ is the vegetation/forests layer thickness and $\theta i$ is the incident angle. $\kappa_e$ is calculated using $\kappa_e = n_0(\sigma_a + \sigma_s)$, where $n_0$ is the number of scatterers per $m^3$, and $\sigma_a$ and $\sigma_s$ are the absorption cross section and the scattering cross section of a single scatterer, respectively. There are two key assumptions in this method: (1) the positions of the scatterers are statistically homogeneous in 3D; (2) each scatterer is uniformly illuminated. These two assumptions are invalid for most of the vegetation/forests. For example, the trees have trunks, branches and leaves in a correlated structure and there are gaps among branches and different trees.

Recently, we have started the advanced physical model of Numerical Maxwell Model of 3D (NMM3D) full wave simulations of vegetation/forests. We develop the hybrid method for this, based on the rigorous solutions of Maxwell equations. This method is a hybrid of the off-the- shelf technique (e.g. HFSS) and newly developed techniques. The newly developed techniques are the three key steps of the hybrid method: (1) calculating the T matrix of each single object using vector spheroidal waves, (2) vector spheroidal wave transformations, and (3) solving Foldy-Lax multiple scattering equations (FL) for all the objects. The T matrix relates the incident fields to the scattered fields for an arbitrarily-shaped scatterer. Previously, vector spherical wave expansions were used for T matrix, where a circumscribing sphere is defined. However, when the objects are closely packed, it is impractical to enclose each object by a spherical surface without overlap. In general, spheroidal surfaces are more compact to enclose closely packed objects. Thus, vector spheroidal wave expansions are used, which are more complicated than the spherical waves. To extract the T matrix for an arbitrary-shape object, the off-the-shelf technique HFSS is used. HFSS enables us to perform full wave simulations of single objects with complicated structures. It is noted that the T matrix extraction method also works for those requiring a spheroidal surface with a large aspect ratio (e.g. branches with leaves). We develop robust numerical methods to perform wave transformations for vector spheroidal waves, which is also called addition theorem. Finally, the extracted T matrices for the single objects are substituted to FL, and the FL is solved with the use of the numerical wave transformations. In solving FL, the multiple scattering of all the objects is calculated.

We illustrate the hybrid method using several complicated objects. For three objects, it is feasible to simulate them with the HFSS brute force method to provide validation. However, the HFSS brute force method is impractical computationally for large problems including lots of objects and empty space such as vegetation/forests, while the hybrid method can still operate with available computation resources. The preliminary results show that the NMM3D full wave simulation method can lead to much greater transmission through the vegetation than the conventional methods of RTE and DBA.

# Stochastic Load Balancing on Unrelated Machines (TOWNER_15)


## Anupam Gupta[1], Amit Kumar[2], Viswanath Nagarajan[3], Xiangkun Shen[3]

[1]*Department of Computer Science, Carnegie Mellon University, Pittsburgh, PA*

[2]*Department of Computer Science and Engineering, IIT Delhi, Delhi, India*

[3]*Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor, MI*



We consider the problem of makespan minimization: i.e., scheduling jobs on machines to minimize the maximum load. For the deterministic case, good approximations are known even when the machines are unrelated. However, the problem is not well-understood when there is uncertainty in the job sizes. We consider a natural stochastic setting where the size of a job $j$ on machine $i$ is a random variable $X_{ij}$. Sizes of different jobs are independent of each other. Unlike a lot of prior work, our approach can handle arbitrary distributions. The goal is to find a fixed assignment of jobs to machines, to minimize the expected makespan—i.e., the expected value of the maximum load over the $m$ machines. For the identical machines special case (when the size of a job is the same across all machines), a constant-factor approximation algorithm has long been known. However, the problem has remained open for the case of unrelated machines where each job has a different size on each machine.

Our main result is the first constant-factor approximation for the stochastic problem on unrelated machines. The main technical challenge we overcome is obtaining an efficiently computable lower bound for the optimal solution. We provide an exponential-sized linear program that we argue gives a strong lower bound. Then we show how to round any fractional solution to satisfy only a small subset of the constraints, which suffices to bound the expected makespan.

# Pressure-Tunable Photonic Band Gaps in an Entropic Crystal (TOWNER_17)


## Rose K. Cersonsky[1], Julia Dshemuchadse[2], James Antonaglia[3], Greg van Anders[3], Sharon C. Glotzer[1,2,3,4,5]

[1] *Macromolecular Science and Engineering Program, University of Michigan, Ann Arbor MI*

[2] *Department of Chemical Engineering, University of Michigan, Ann Arbor, MI*

[3] *Department of Physics, University of Michigan, Ann Arbor, MI*

[4] *Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI*

[5] *Biointerfaces Institute, University of Michigan, Ann Arbor, MI*



Materials adopting the diamond structure possess useful properties in atomic and colloidal systems and are a popular target for synthesis in colloids where a photonic band gap is possible. The desirable photonic properties of the diamond structure pose an interesting opportunity for reconfigurable matter: can we create a crystal able to switch reversibly to and from the diamond structure with a photonic band gap in the visible light range? Drawing inspiration from high-pressure transitions of diamond-forming atomic systems, we design a system of polyhedrally-shaped colloidal particles that transitions from diamond to a tetragonal diamond derivative upon a small pressure change. The transition can alternatively be triggered by changing the shape of the particle *in-situ*. Additionally, our modeling and simulation approach bridges multiple length-scales by linking bulk property calculations to molecular simulations. We propose that the transition provides a reversible reconfiguration process for a potential new colloidal material and draw parallels between this transition and phase behavior of the atomic transitions from which we take inspiration.

# Alloying Boron into InGaN Active Layers to Create Higher-Power, Higher-Efficiency LEDs (TOWNER_19)

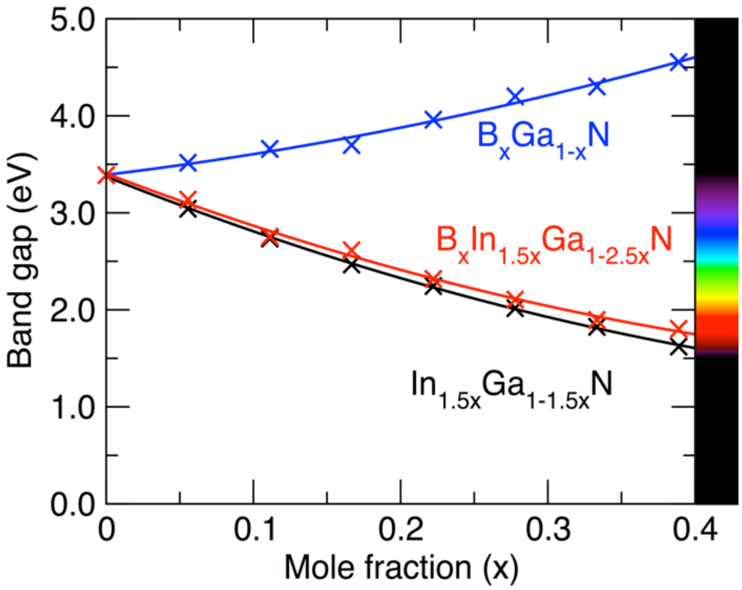

**Logan Williams[1], Kevin Greenman[2], Emmanouil Kioupakis[1]**

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

[2] *Department of Chemical Engineering, University of Michigan, Ann Arbor, MI*


InGaN-based visible light-emitting diodes (LEDs) are commercially prevalent in solid- state lighting and displays, but their efficiency and operating power are still hampered by Auger recombination, which occurs when high concentrations of charge carriers (electrons and holes) are present in the material and produces waste heat instead of light. There exists an optimal carrier density where light-producing radiative recombination is dominant over the wasteful Auger recombination (dominant at high carrier densities) and defect recombination (dominant at low carrier densities). Carrier density in a device for a given current density (input power) could be optimized by changing the volume of the active layer, where radiative recombination produces light. However, the thickness of the active InGaN layer is restricted by strain from a lattice size mismatch between InGaN, with larger indium ions, and the surrounding GaN layers, with only smaller Ga atoms.

The incorporation of boron, a smaller group-III element, into InGaN alloys is a promising method to eliminate the lattice mismatch and realize high-power, high-efficiency visible LEDs by using thick active regions. We have applied predictive, *ab initio* calculations based on hybrid density functional theory (DFT) to investigate the thermodynamic, structural, and electronic properties of BInGaN alloys. Our calculations show that BInGaN alloys have significantly reduced lattice mismatch with GaN compared to InGaN, while retaining the desired range of band gaps that make InGaN alloys able to emit visible light and function as LED active layers.
Our thermodynamics calculations indicate that inclusion of up to 5% of boron should be possible in BInGaN using current growth techniques. Our results indicate that BInGaN alloys are promising for fabricating nitride heterostructures with thick active regions for high-power, high- efficiency LEDs.



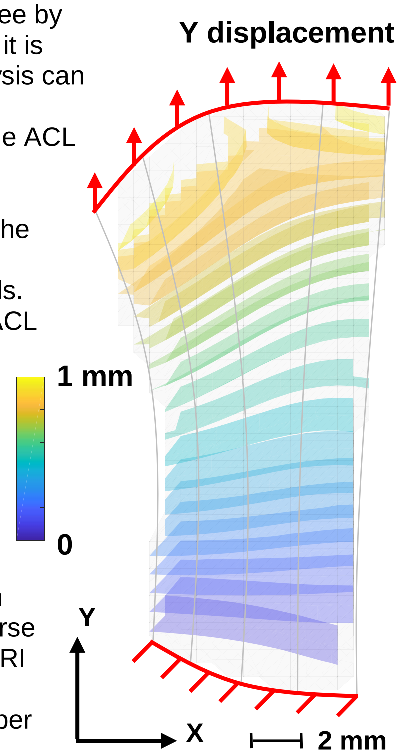
# State-of-the-Art Imaging and Inverse Methods Advance Mechanics-Based Approach to ACL Injury Prevention and Treatment (TOWNER_21)


## Callan M. Luetkemeyer, Ellen M. Arruda

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


Anterior cruciate ligament (ACL) injury rates continue to rise, particularly among women and young people. These injuries are associated with an increased risk of knee osteoarthritis, usually within 10 years of the injurious event, and those with complete ACL tears require surgical reconstruction in order to resume normal activity. Due to the injury's prevalence and its impact on quality of life, there is substantial interest in determining its risk factors – the anatomical features and movement strategies that make an individual more prone to ACL injury.

The function of the ACL is mechanical; it provides stability to the knee by restricting motion between the femur and tibia and it becomes injured when it is overstrained. Thus, computational mechanics tools like finite element analysis can help us perform virtual experiments to systematically examine the effects of possible risk factors on ACL strain. However, current material models for the ACL are unable to accurately predict tissue-level deformation. Ligaments are anisotropic, meaning their response to mechanical stress depends on the direction of loading, due to their highly aligned collagen fibers. This allows the influence of structural features to be more pronounced, producing inhomogeneous deformation – a non-starter for traditional modeling methods. Therefore, the aim of this work is to build accurate material models for the ACL using full-field methods, which capitalize on the deformation inhomogeneity that has made this problem historically difficult to solve.




A new specialized displacement imaging technique – displacement-encoded MRI – was used to measure the first full-volume displacement maps of the ACL bundles under tension. The figure at right shows a set of experimentally measured 3D displacement contours for a posterolateral bundle of the ACL. The tibia of the specimen was held fixed while the femur was displaced 1 mm in the positive Y direction. The displacement contours follow the shapes of the bony attachments (shown in red). The virtual fields method (a computationally inexpensive full-field inverse method) was adapted to extract material parameters from the full-volume MRI displacement data. This method accounted for structural features like the curved bone boundaries (shown by the red lines) and position-dependent fiber direction (shown by the gray fibers), while using the entire measured displacement map to inform the material model fit. Based solely on this mechanical data, the material parameters found indicate that the two ACL bundles have significantly different degrees of collagen alignment ($p < 0.01$). This is a known microstructural difference between the bundles which has not been detected by previous modeling efforts.

This work advanced the forefront of knowledge on ligament mechanics by demonstrating that full-field methods can be used to decouple material from structural properties, a previously unattainable task with traditional methods. These accurate material models will be used in whole-knee finite element models to identify ACL injury risk factors and understand the mechanisms by which injuries occur, as well as serve as a benchmark for the mechanics of tissue-engineered ACL replacement grafts.

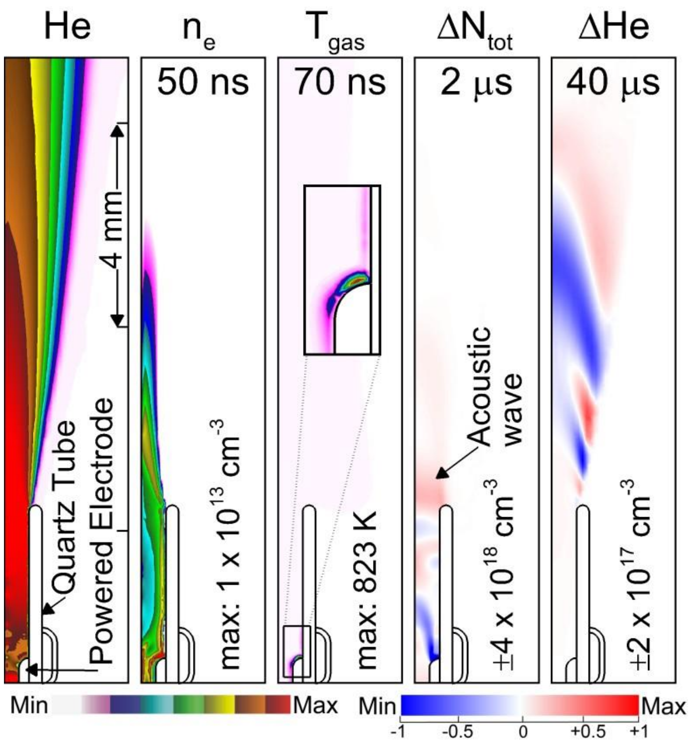
# Plasma-Induced Flow Instabilities in Atmospheric Pressure Plasma Jets (TOWNER_23)


## Amanda M. Lietz[1], Eric Johnsen[2], Mark J. Kushner[3]

[1]*Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI,*
[2]*Departtment of Mechanical Engineering, University of Michigan, Ann Arbor, MI*
[3]*Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*


Atmospheric pressure plasma jets (APPJs) are a type of low temperature plasma source which produce fluxes of reactive species onto surfaces. These reactive species produce beneficial effects including cancer treatment, disinfection, and produce preservation. An APPJ typically consists of a dielectric tube through which a rare gas flows, with a high voltage electrode in or on the tube. The driving voltage is typically pulsed, generating plasmas that last hundreds of nanoseconds, initializing nonequilibrium chemistry can continues for minutes.

One challenge with these devices is producing a controlled, consistent, and well understood mixture of reactive oxygen and nitrogen species (RONS). Recently, experimental observations of flow instabilities have been made – previously laminar gas jets become unstable when the plasma is switched on. These instabilities can alter the RONS generation by changing the mixing of rare gas with the surrounding air. There have been many hypotheses regarding the physical mechanism of these flow instabilities, and understanding their cause is essential to controlling the RONS produced.




In this paper, the results from a 2-dimensional plasma hydrodynamics model of an APPJ are discussed. The device modeled consists of helium flowing through a 1 mm diameter quartz tube, with an annular high voltage electrode inside the tube, shown at the left. The plasma propagates in tens of ns as an ionization wave beginning at the powered electrode, producing the electron densities shown in the figure ($n_e$).

Highly localized gas heating near the powered electrode, shown by the plot of $T_{gas}$, produces temperatures of 823 K in a small region on the timescales of the discharge pulse (tens to 100 ns). After the pulse, the expansion of this heated gas produces an acoustic wave, shown as oscillations in the total number density ($\Delta N_{tot}$). This acoustic wave initiates an instability in the shear layer where the rare gas meets the surrounding air. This shear instability grows and results in oscillations of the mixing region between the helium and surrounding air, shown by changes in He density ($\Delta$He). This mechanism is consistent with several experimental observations, including imaging which shows flow disturbances occurring at the discharge frequency and propagating with the flow velocity, which would be expected based on this mechanism.

## Unsupervised Learning for Depth Estimation and Color Correction of Underwater Imagery (TOWNER_25)


### Katherine A. Skinner

*Robotics Institute, University of Michigan, Ann Arbor, MI*



In recent years, advances in computer vision and deep learning have led to breakthroughs in perceptual capabilities of robotic systems. Yet there remain challenges to extending these advances to all domains. In particular, the underwater domain presents unique environmental conditions to robotic systems that exacerbate current challenges in perception. The process of underwater light propagation hinders efforts to transfer computer vision methods developed on land to marine applications. Furthermore, training data and ground truth labels necessary for supervised learning approaches are often difficult or impossible to collect in subsea environments. This work presents novel frameworks for using physics-based models of environmental conditions in computer vision and unsupervised learning contexts to overcome challenges to marine robotic perception. Specifically, this work focuses on image restoration and dense depth map estimation from raw underwater imagery. Experiments are presented with real underwater data collected at different field sites, with ground truth structure and color to provide both quantitative and qualitative evaluation of results. We show that our method improves upon traditional and state-of-the-art approaches. Although this work focuses on the underwater domain, its aim is to work towards robust perception systems for deploying robotic platforms in natural and unstructured environments often encountered in field robotics.

# Advanced Graduate Student Research (AGSR) Poster Session

# 11:00 am – 12:30 pm

## Duderstadt Atrium and Connector

# Programming Self-Organization of Colloidal Material at Miniature Scale (AGSR_2)


## Mayank Agrawal[1], Isaac R. Bruss[2], Sharon C. Glotzer[1,3,4]

[1]*Department of Chemical Engineering, University of Michigan, Ann Arbor, Michigan*

[2]*School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts*

[3]*Department of Material Science and Engineering, University of Michigan, Ann Arbor, Michigan*

[4]*Biointerfaces Institute, University of Michigan, Ann Arbor, Michigan*



Advancements in self-assembly and top-down fabrication approaches have enabled tailoring of colloidal material, macromolecules and polymers, and nanoparticles in both organic and inorganic fashion to built advance functional materials. In my research, I use coarse-grained particle dynamics and analytical modeling to address building such material that are programmable at the elemental level and are tunable at the macroscopic level. In this talk I will discuss two approaches to this end that use active colloids (colloids possessing propulsion) as the raw material. This choice is motivated by the development in the field of active matter enabling synthesize using a wide variety of materials that can harness environmental energy into propulsion force. In the first approach, the system consists of particles that trigger propulsion only when in-contact with other particles. Such systems can be tuned externally to form and switch among crystals, gels and clusters. Further, these systems possess enhanced transport dynamics, which is also tunable. In the second approach, the active particles are connected end-to-end in a loop. When actuated, the loops fold into programmed shapes while the internal space is available to accommodate additional components such as sensors, controller, chemicals, and communication devices. The shape and motion information is encoded in the arrangement of active particles along the loop. Besides relevance of these systems in understanding the fundamental physics of non-equilibrium systems, they can be used to develop smart materials that can sense, actuate, compute and communicate.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# A Self-Organization Route to Three-Dimensional Chiral Metamaterials (AGSR_5)

## Saman Moniri[1], Tianxiang Lu[2], Ashwin J. Shahani[2]

[1]*Department of Chemical Engineering, University of Michigan, Ann Arbor, MI*

[2]*Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI*

Controlled formation of three dimensional (3D) chiral structures offers a pathway to the realization of new and unusual light-matter interactions, such as negative refraction, perfect absorption, and enhanced nonlinear optical properties. Top-down lithographic methods have successfully been used to fabricate complex 3D chiral architectures with micrometer scale characteristic dimensions, but their wider application toward large-area materials remains challenging. Here, we report a bottom-up route based on directional solidification of eutectic spirals. During solidification of a eutectic melt, the liquid phase-separates simultaneously into two (or more) solid phases which self-organize into alternating monoliths. We demonstrate a class of faceted eutectic spirals in the Zn-Mg alloy system. By independently tuning the thermal gradient (G) as well as velocity (V) of the solidification front, we steer the system down different kinetic pathways to produce various eutectic morphologies, trapping the system as metastable, two-phase conical eutectic spirals with opposite chirality at moderate G and high V. To better understand the emergence of such structures from a parent liquid phase, we have conducted a multimodal investigation using X-ray nanotomography, 3D electron backscatter diffraction, and further electron microscopy. Our correlative imaging workflow provides new insights into the complex morphology, crystallography, and underlying growth mechanism of the faceted eutectic spirals. It is anticipated that these results will provide the necessary benchmark data for simulations (e.g., phase field) of multiphase solidification patterns.

# Interannual Variability and Seasonality of Precipitation in the Indus River Basin (AGSR_9)

## Samar Minallah[1,2], Valeriy Y. Ivanov [2]

[1]*Department of Climate and Space Sciences and Engineering, University of Michigan Ann Arbor, MI*

[2]*Department of Civil and Environmental Engineering, University of Michigan Ann Arbor, MI*

The Indus River Basin is highly vulnerable to water scarcity due to increasing population, unsustainable management practices, and climate change. Its long-term susceptibility is argued to be the highest in Asia, yet the regional hydroclimate and its variability remain poorly understood. Despite focus of countless studies, the future of water security here is uncertain and unpredictable.

Responding to a knowledge gap stemming from the lack of a comprehensive analysis of basin-scale water input, the primary objective of this study is to address precipitation temporal variability over the Indus Basin, its sub-regional variations, trends, and uncertainties – all representing crucial information for the development of robust inferences on the present hydroclimatic regime of the basin and its future. The analysis relies on multiple precipitation products to address variability of annual and seasonal precipitation and explores the impacts of one of the major climatic drivers in the region, the South Asian Monsoon (SAM), as well as the linkage of its temporal behavior with El Niño–Southern Oscillation (ENSO). This study has the specific objectives to examine (a) precipitation variations at meso/sub-basin spatial scale and the differences in the seasonal cycles in these sub-regions; (b) the short- (decadal and sub-decadal) and long-term (multi-decadal) trends in annual and seasonal precipitation; (c) Monsoon onset and withdrawal date dynamics, employing criteria and methods specific to the Indus Basin; (d) detectable links between precipitation metrics and ENSO; and (e) performance of commonly used precipitation products, especially in the extreme, high-altitude orographic regions of the basin, and their commonalities in terms of how they represent spatiotemporal precipitation distribution.

In our findings, we uncovered remarkable alternation of long-term positive and negative precipitation trends in the basin over the past half century. These trends have led to substantial changes in water input over the region at the time scales comparable to climate assessment periods (30 years) and therefore this high intrinsic variability must be accounted for in climate change adaptation studies. Reconstructed dates of onset and withdrawal of SAM also exhibit alternating trends, but their dominant modes differ from that of annual precipitation. Higher frequency variability in ENSO is likely to have a pronounced impact on Monsoon onset and duration in the studied region.

## Behaviorally Stable Vehicle Platooning for Energy Savings (AGSR_13)

### Xiaotong Sun, Yafeng Yin

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

A cooperative vehicle platoon is a set of vehicles driving together with low in-vehicle distance enabled by the connected and automated vehicle technology. One of the major benefits of vehicle platooning is energy savings due to air drag reduction. However, as vehicles at different positions in a platoon save differently from the platooning, e.g., the lead vehicles may save little, some drivers or owners of vehicles may not be willing to join or stay in the platoon even if they are advised to do so, yielding behaviorally unstable platoons. The instability further lead to chaos in traffic flow, which is likely to bring unnecessary traffic congestions.


(a) Greater air drag reduction (b) Smaller air drag reduction

Figure 1. A toy example of unevenly distributed energy savings

As such behavioral side of the problem has been drawn little attention in literatures, this study intends to fill this void by focusing on the drivers and owners' economic consideration of platooning. We envision a freeway system where vehicles are capable of platooning but each platoon has limited size. A novel utility function is proposed to measure a vehicle's benefit in platooning. Based on that, a mathematical programming model is established to find the optimal platoon formation that specifies which vehicles should be platooned together and their platoon speeds as well as positions to achieve the maximum system benefit. A benefit allocation mechanism, either charges or compensates the vehicles, is then created to incentivize them to form and maintain the desired platoon formation. The model framework is further extended to the setting with an environmental concern, where the proposed mechanism has been shown to benefit not only the vehicles, but also the whole society by bringing greater reductions on traffic emissions.

# Modeling Climate Resilience in Smallholder Agricultural Systems: An Agent-Based Approach (AGSR_15)

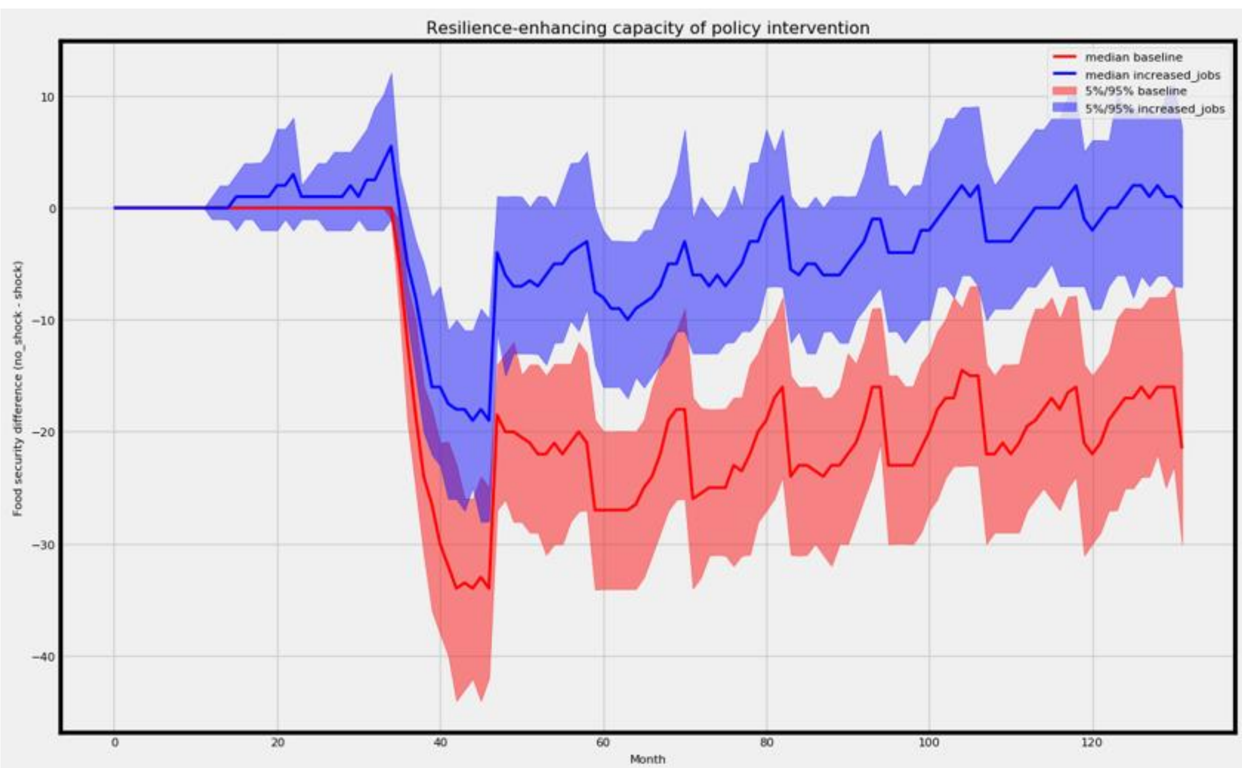

## Tim Williams, Seth Guikema

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


While many definitions of resilience have been explored in agricultural development contexts, resilience is seldom assessed in quantitative modeling applications. Given the great risk that climate variability poses to smallholder farming systems, quantifying and identifying potential enhancements to future resilience should be prioritized.

In this study we present and demonstrate a method for quantifying resilience in a smallholder agricultural system. Resilience is conceptualized as the extent to which region-wide food security is compromised by exposure to an external climate shock. Through the use of an agent-based model, we quantify resilience of an Ethiopian smallholder farming system, and explore the resilience-enhancing capacity of selected development strategies. We find that increasing the availability of urban employment opportunities can lead to significantly lower impacts following a drought event, and is thus a potential mechanism through which agricultural resilience can be increased.

More generally, our approach allows us to evaluate and prioritize policy interventions with respect to their effect on resilience - a critical competency for a wide range of systems threatened by climate change.



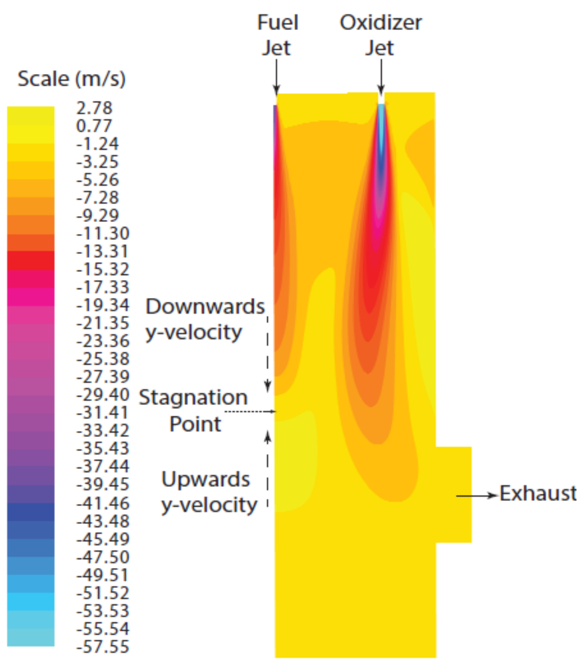
## A Numerical Study of Confined Turbulent Jets for High-Temperature Homogeneous Combustion (AGSR_16)


### Kumar Aanjaneya, Weiyu Cao, Arvind Atreya

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



Homogeneous Combustion (HC) and its various variants have emerged as attractive techniques to abate NOx emissions (produced via the thermal route or Zeldovich mechanism). It has been conclusively shown in existing literature that Damkohler number (Da) (ratio of reaction rate and advective transport rate) must be very close to unity for homogeneous combustion. High-temperature applications such as industrial heating are often accomplished by using “enriched" oxidizers. Extending the concept of HC to serve industrial needs is greatly desirable but can be challenging as enriched oxidizers would accelerate reaction rates, and hence increase Da, causing a shift to the conventional mode of combustion with high NOx emissions. This work numerically studies the feasibility of attaining HC with enriched oxidizers under near-stoichiometric conditions in a setup that can be easily scaled up for industrial usage. The effect of fuel jet momentum on NOx emissions is also studied and presented. It is seen that quite counter-intuitively, the increase of fuel jet momentum leads to an increase in NOx emissions. CO and hydrocarbon emissions are found to be dependent only on equivalence ratio and follow expected trends. The highly complex flow in the parallel-jet furnace is sought to be explained by breaking it down into a set of canonical flows and using parameters related to them. Stagnation distance is suggested as a length scaling parameter to describe arrangements with multiple confined turbulent jets. It is shown to perform well for flows under the jets by yielding curves which are independent of chemistry.

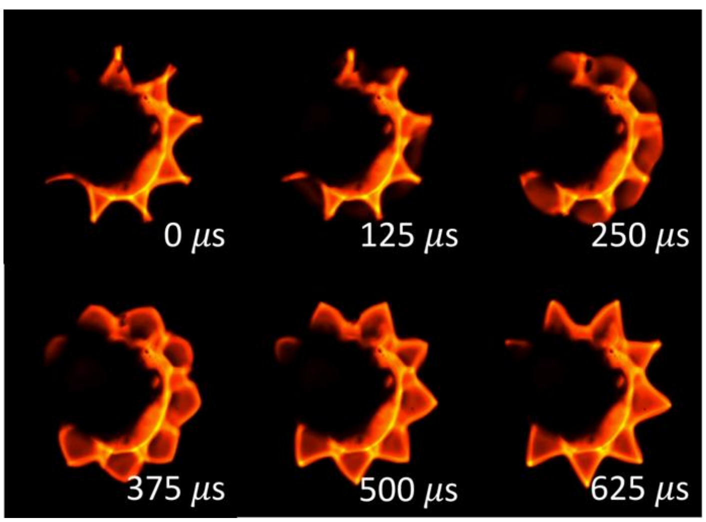
## Investigation on Coupling Between Plasma Self-Organization and Streamer-Induced Capillary Oscillations in Bubbles in Water (AGSR_17)


### Janis Lai, John E. Foster

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


Plasma discharges in bubbles are of interest in plasma-based liquid activation applications such as water purification due to its ability to produce myriad of reactive species such as hydrogen peroxide and ozone which are effective against contaminants in water. Optimization of production and transport of plasma-derived reactive species rely on understanding of mechanisms behind streamer propagation in bubbles in water. Pulsed discharges have been observed to induce capillary oscillations on the bubble interface in previous studies, which can also lead to sympathetic oscillations in nearby bubbles. As a result, capillary oscillations can alter the geometry of the bubble and affect subsequent streamer propagation, possibly leading to self-organization of streamers inside bubbles.

In this study, a 2-D plasma-in-liquid Hele-Shaw-like cell is used to study the plasma-liquid interface region and streamer propagation in air bubbles. Various capillary wave modes are excited on bubble boundary by altering parameters such as excitation frequency and water conductivity. Discharges inside bubbles are imaged using a high-speed camera to assess coupling between capillary oscillations and self-organization of streamers. Additionally, streamer hopping and capillary oscillations coupling between bubbles attached to excited electrode and bubbles in bulk liquid are investigated. This work gives insight into the influence of plasma driven mechanical effects on the modification of plasma production and propagation modes, ultimately influencing reactive oxygen and nitrogen species' spatial and temporal transport into the bulk liquid. This basic insight may yield understanding on how to improve the efficiency of plasma water purification systems.



# An Infrared Thermal Imaging Based Method for Personalized Thermal Comfort Assessment (AGSR_19)


## Da Li, Carol C. Menassa, Vineet R. Kamat

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



Understanding occupants' thermal comfort is essential for the operation of building Heating, Ventilation and Air Conditioning (HVAC) systems. Existing studies of the "human-in-the-loop" control strategy generally suffer from (1) the excessive reliance on cumbersome human feedback; and (2) the intrusiveness caused by the conventional data collection methods (e.g., wrist-worn sensors). To address these limitations, this study investigates the low-cost thermal camera as a truly non-intrusive data collection approach to interpret occupants' thermal comfort in real time using skin temperature features extracted from human face. This approach is able to automatically detect the presence of occupants, extract facial regions, measure skin temperature, and interpret thermal comfort with minimal interruption of the building occupants. The proposed approach is verified and validated using the facial skin temperature data collected from twelve occupants in a climate chamber experiment consisting of cooling, heating, and steady-state scenarios. The results demonstrate the proposed approach can interpret occupants' thermal comfort with an accuracy of 85% and also suggest that the skin temperature of ears, nose and cheeks are most indicative of thermal comfort.

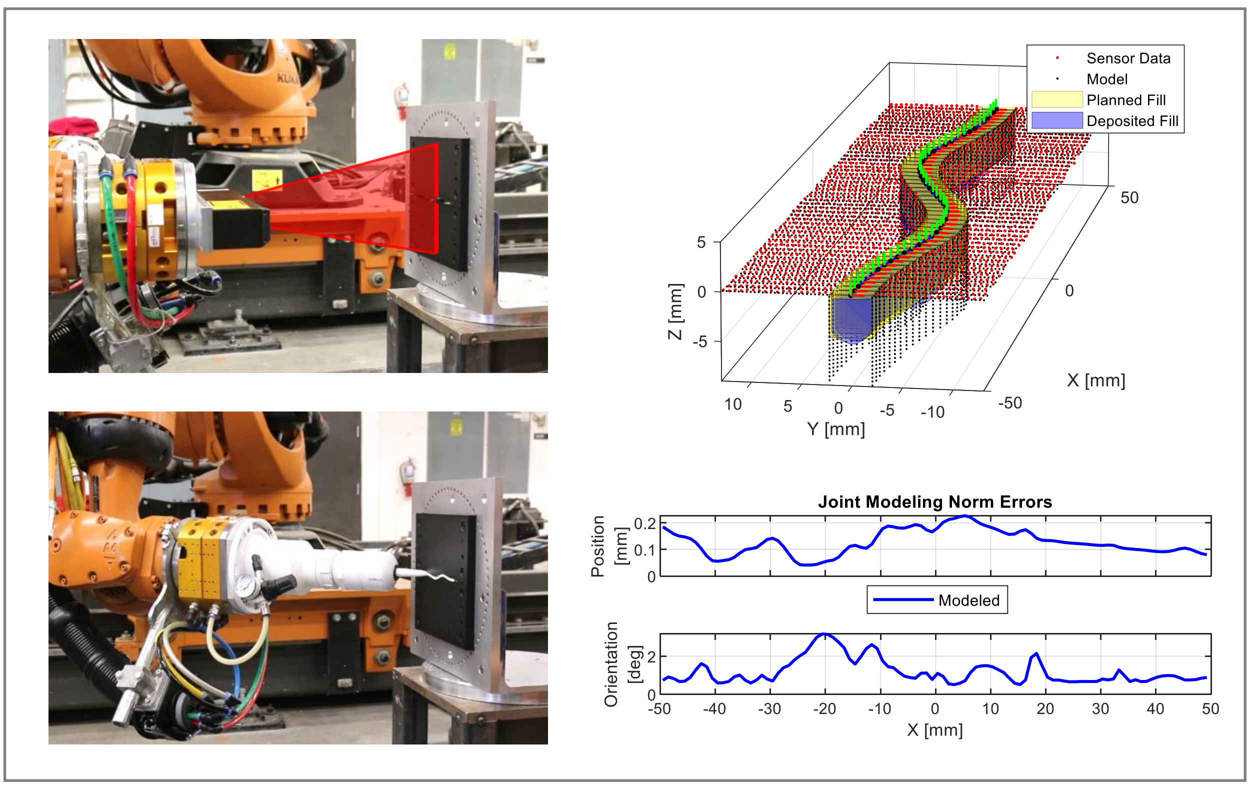
# Perception and Planning for Adaptive Robotized Construction Joint Filling (AGSR_20)


## Kurt M. Lundeen[1], Vineet R. Kamat[1], Carol C. Menassa[1], Wes McGee[2]

[1]*Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI*
[2]*Taubman College of Architecture and Urban Planning, University of Michigan, Ann Arbor, MI*



This research explores a means by which a construction robot can leverage its sensors and Building Information Model (BIM) to perceive and model the actual geometry of its workpieces, adapt its work plan, and execute work in a construction environment. The adaptive framework uses the Generalized Resolution Correlative Scan Matching (GRCSM) construction component model fitting technique for model registration, a new formulation for fill plan adaptation, and new hardware for robotic material dispensing. Joint filling is used as a case study to demonstrate the formulation of an adaptive plan and evaluate a robot's ability to perform adaptive work in environments where the actual joint to be filled deviates in location and geometry from its designed counterpart. The robot was found capable of successfully filling the joint by identifying the true position and orientation of the joint's center with a mean norm positioning error of $0.13\ mm$ and orientation error of $1.2°$. The adaptive framework appears promising for a range of construction activities, including those involving objects of complex geometry and detailed work.

# Personalized PageRank Dimensionality and Algorithmic Implications (AGSR_21)


## Daniel Vial, Vijay Subramanian

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


Many systems can be represented as graphs, sets of objects (called *nodes*) and pairwise relations between these objects (called *edges*). These include Internet, which contains websites (nodes) that are connected via hyperlinks (edges); social networks like Twitter, which contains users (nodes) that follow one another (edges); and the human brain, which contains neurons (nodes) that exchange signals through chemical pathways (edges). To study graphs, researchers in diverse domains have used *Personalized PageRank* (PPR). Informally, PPR assigns to each node $v$ a vector $\pi_v$, where $\pi_v(w)$ describes the relevance of node $w$ to node $v$. PPR has proven in many applications. For example, Twitter has used PPR to recommend who users should follow (user $v$ may wish to follow user $w$ if $\pi_v(w)$ is large). Unfortunately, computing all $n$ PPR vectors for a graph of $n$ nodes has complexity $O(n^3)$, which is infeasible for massive graphs arising in modern domains (like Twitter).

In this work, we argue that the situation is not so dire. In particular, we provide an algorithm to estimate all $n$ PPR vectors with bounded error (in the $l_1$ norm) and with sub-quadratic complexity (i.e. complexity $O(n^c)$ for some $c < 2$). To the best of our knowledge, our scheme improves upon all algorithms found in the literature, the most competitive of which have complexity $O(n^2 log(n))$. We note that our accuracy guarantee holds for any graph, while our complexity guarantee holds for a certain class of graphs. We believe that this class contains realistic models of real-world networks; as an example, we devise a Twitter-like model, which contains a few highly-connected nodes -- modeling celebrities with millions of Twitter followers -- and far more moderately-connected nodes -- modeling “normal” users.

The fundamental reason why our algorithm outperforms existing methods is that, while existing methods estimate each of the $n$ PPR vectors separately, our algorithm exploits the structure of these vectors to estimate them jointly (and thus more efficiently). Specifically, we prove that the effective dimension of the set of PPR vectors vanishes relative to $n$ in our setting; put differently, we show that only a vanishing fraction of these vectors are truly independent. This structural insight allows us to directly estimate only the vanishing fraction of independent vectors, and then to use these vectors to indirectly estimate the others. We believe that this structural insight can used to design more efficient algorithms in other settings, suggesting that our analysis may lead to further advancements.

# Nanoscale Probing of Interlayer Bonding in 2D Layered Heterostructure (AGSR_22)


## Hossein Rokni, Wei Lu

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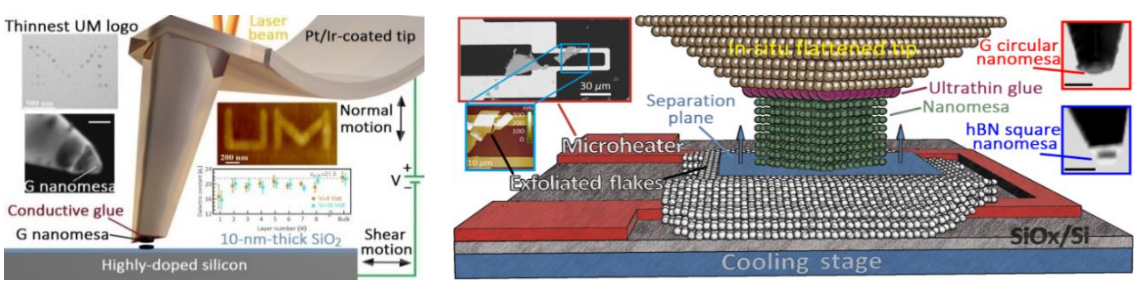
The isolation of two-dimensional (2D) layered materials and the possibility to combine them in vertical stacks has created a new paradigm in materials science: van der Waals (vdW) heterostructures. Such a concept offers a variety of new physical properties that do not exist in nature, thanks to the full spectrum of electronic properties in 2D materials, from conducting graphene, to semiconducting $MoS_2$, to insulating hBN. Both 2D materials and their vdW heterostructures have already proven fruitful for various high-performance, ultrathin, and flexible devices to be used in electronic (e.g., super-fast transistors, chemical and thermal sensors, and flexible touch-screen displays), energy storage (e.g., high-storage, fast-charging batteries and ultracapacitors), optoelectronic (e.g., light-emitting diodes, photodetectors and optical modulators) and biomedical (e.g., anticancer, tissue engineering, drug delivery, bioimaging, biosensing and antimicrobial) applications. Since intrinsic ultrahigh surface to volume ratio in layered materials dictates an extremely strong and dominant vdW force in many processes related to not only synthesis, transfer and manipulation of 2D materials but also fabrication, integration and performance of devices incorporating these materials, precise nanoscale quantification of their weak interlayer vdW bonding is of fundamental and technological importance for the mass production and continued development of such promising materials.

Herein, we exploit conductive atomic force microscopy (AFM) combined with molecular dynamics simulations to report the first nanoscale in situ measurements of interlayer electrostatic/mechanical properties of 2D materials and their vdW heterostructures through well-defined interactions between AFM tip-attached 2D crystal nanomesas (G, hBN and $MoS_2$) and mechanically exfoliated 2D crystal flakes. We first qualitatively study the mechanical response of interlayer vdW bonding to external shear or normal forces by displacing two adjacent layers relative to one another in a direction parallel or normal to the basal plane of 2D crystals, respectively. We next quantify the effect of airborne contaminants and humidity (as an inevitable part of any vdW heterostructures) on the interfacial adhesion level at the G/hBN, hBN/$MoS_2$, G/$MoS_2$, G/$SiO_2$, hBN/$SiO_2$ and $MoS_2$/$SiO_2$ heterointerfaces. We also address quantitatively to what degree contaminated heterointerfaces can recover their interfacial adhesion energy by controlling the temperature of nanocontact interfaces in the range of -15–300°C by microheaters on the top and a cooling stage underneath the $SiO_2$/Si substrate. Finally, we precisely quantify the effect of layer number and electric field on the dielectric constant of few-layer graphene by applying a bias voltage (up to 10V) between conductive AFM probe and $SiO_2$/Si substrate. Accurate determination of interlayer vdW properties of 2D materials coupled with our unique nanoscale manipulation setup with ultrahigh force-displacement resolution has allowed us to successfully produce UM's thinnest possible logo by only mono, bi and trilayer graphene flakes.



# Design of an Indoor Localization System Based on Occupancy Grid Mapping in Visual SLAM (AGSR_25)


## Lichao Xu, Vineet R. Kamat, Carol C. Menassa

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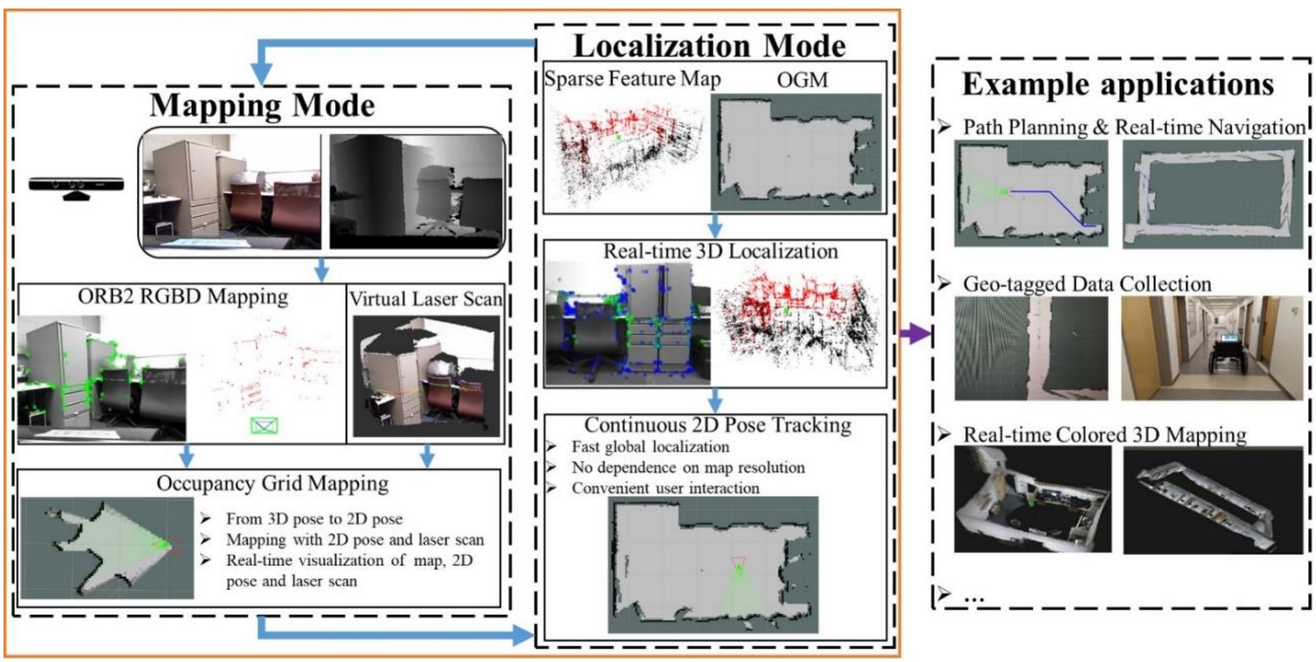
Real-time locating systems (RTLS) make possible accurate and timely information about mobile resources and have been increasingly adopted in building and civil infrastructure environments for improved material management, work productivity, onsite safety and project planning and scheduling. However, since the existing RTLS solutions are mostly based on either wireless technologies, fiducial makers, or Lidar-based Simultaneous Localization and Mapping (SLAM), they inevitably suffer from some of the following disadvantages: low accuracy, reliance on existing facilities, labor-intensive environment instrumentation, and economic infeasibility for wide deployment. This paper introduces an ORB RGB-D SLAM based indoor RTLS that can be readily adapted and applied to building or civil infrastructure applications, while addressing the above limitations. Besides the original sparse feature map built by the visual SLAM (vSLAM), the system also builds and maintains an additional 2D occupancy grid map (OGM), with the 3D camera poses estimated by the vSLAM and the laser scans extracted from the point cloud observed from the camera at those poses. Simultaneously, the OGM is overlaid with real-time camera pose (position and orientation) and observation (virtual laser scan) via Robot Operating System (ROS) visualization tools. These designs not only provide more intuitive pose information with users and allow them to interact with the system, but also open up the possibilities of path planning and continuous navigation which cannot be implemented directly on the vSLAM's original feature map. The localization accuracy of the system is tested and evaluated with a set of pre-installed fiducial markers, which proves its feasibility and applicability in indoor building and construction applications.

## Optimizing Inspection Routes in Pipe Networks (AGSR_30)


### Thomas Ying-Jeh Chen[1], Connor Thomas Riley[2], Pascal Van Hentenryck[2], Seth David Guikema[2]

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[2] *Department of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA*



The inspection of aging water distribution pipes is a vital process for utilities to aid better decision making for risk-based management. To facilitate cost-efficient deployment of inspection robotics, a process that finds high risk pipe while accounting for the tool limitations is needed. We formulate the problem as an integer program, and explore a variety of methods to identify optimal routes: branch and bound, constraint generation, breadth-first search, depth-first search, and depth-first search with pruning. While only three factors are used to characterize tool limitations, the formulation can be extended to include technology-specific complexities in real world applications. Empirical trials suggest that tree searches are most efficient when the allowable path lengths are short, but scales exponentially as the limit grows. Network preprocessing, where edges of the same pipe type are joined, and the removal of short edges can provide large computation time reductions while returning near-optimal solutions.

## Laser-Wakefield Accelerators for High-Resolution X-Ray Imaging of Complex Microstructures (AGSR_39)

**Amina E. Hussein[1], N. Senabulya[2], O. Finlay[3,4], Y. Ma[1,3,4], M.J.V. Streeter[1,3,4], B. Kettle[5], S.J.D. Dann[3,4], E. Gerstmayr[5], F. Albert[6], N. Bourgeois[7], S. Cipiccia[8], J.M. Cole[5], I.G. Gonzalez[9], A. Higginbotham[10], D.A. Jaroszynski[4,11], K. Falk[12], K. Krushelnick[1], N. Lemos[6], N.C. Lopes[5,13], C. Lumsdon[10], O. Lundh[9], S.P.D. Mangles[5], Z. Najmudin[5], P.P. Rajeev[7], M. Shahzad[4,11], M. Smid[12], R. Spesyvtsev[4,11], D.R. Symes[7], G. Vieux[4,11], L. Willingale[1,3,4], J.C. Wood[5], A. Shahani[2], A.G.R. Thomas[1,3,4]**

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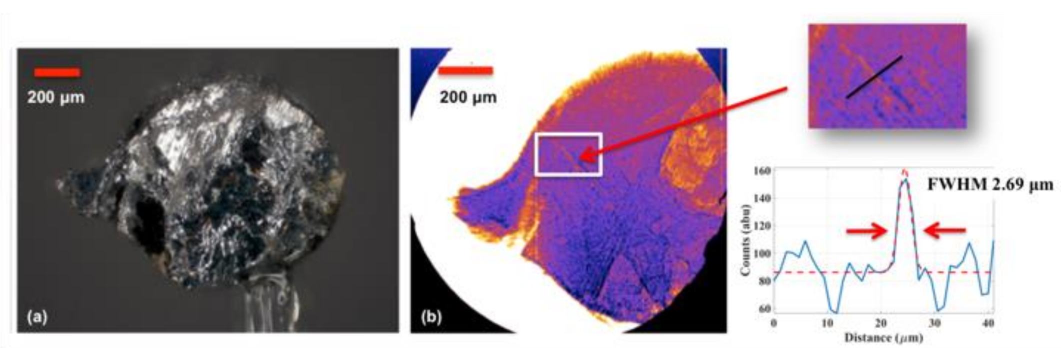
*[13]GoLP/Instituto de Plasmas e Fusao Nuclear, Instituto Superior Tecnico, U.L. Lisbon, Portugal*

Laser-wakefield accelerators (LWFA) are a new generation of plasma-based particle accelerators, capable of producing high-energy electron beams. Within the strong focusing fields of the wakefield, accelerated electrons undergo betatron oscillations, emitting a bright source of X-rays with a micrometer-scale source size. Non-destructive X-ray phase contrast imaging and tomography of heterogeneous materials can provide insight into their processing, structure, and performance. To demonstrate the imaging capability of X-rays from an LWFA, we have examined an irregular eutectic in the aluminum (Al)-silicon (Si) system. The lamellar spacing of the Al-Si eutectic microstructure is on the order of a few micrometers, thus requiring high spatial resolution. We present comparisons between the sharpness and spatial resolution in phase contrast images of this eutectic alloy obtained *via* X-ray phase contrast imaging on the Swiss Light Source (SLS) synchrotron and X-ray projection microscopy *via* a LWFA source. Projection images of the Al-Si sample obtained using LWFA x-rays were 38% sharper and had a 14.27% higher resolution than projection images obtained at the SLS. These results indicate that betatron X-rays from LWFA can be competitive with conventional synchrotron sources for high resolution imaging of eutectics and, more broadly, complex microstructures.



# Accurate Transfer-Power Measurement for Wireless Charging of Electric Vehicles Under Misalignment (AGSR_41)

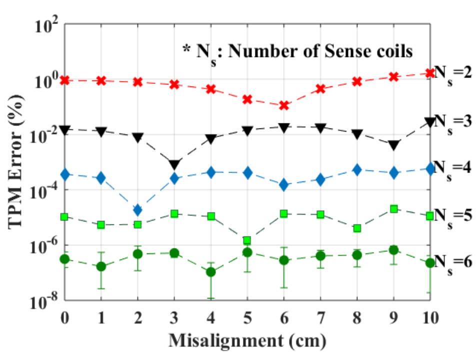

## Sung Yul Chu, Xiaofan Cui, Al-Thaddeus Avestruz

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

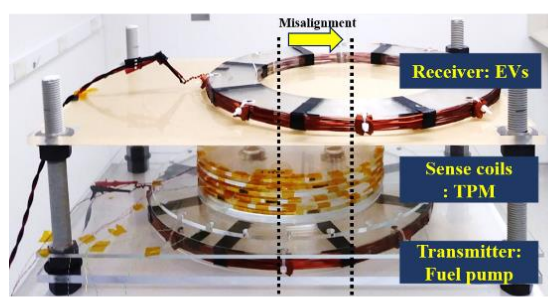


Electric vehicles (EVs) will soon become the dominant mode of ground transportation with wireless power transfer (WPT) as one of the primary modes of charging. For fairness, the cost for lost energy must be appropriately assigned among the stakeholders. To do this, losses in WPT must be disaggregated for metering. Misalignment between a vehicle and a charger degrades both power and efficiency. This degradation is a financial loss; a mere 1% reduction can cost up to $1 billion worldwide emphasizing the need to accurately measure the transferred power under misalignment. Transfer-power measurement (TPM) provides fair metering for WPT in EVs. TPM employs sense coils between the transmitter coils (Tx) and receiver coils (Rx) to determine the transferred power from the magnetic field. Two sense coils are enough for TPM when the Tx and Rx positions are always fixed. However, misalignment of coils leads to errors which can be corrected by using more sense coils. In this paper, TPM under misalignment using multiple sense coils is introduced, which gives implicit information about the misalignment with a new algorithm. A quadratic approximation of coupling coefficients under misalignment is used to correct the errors. This minimizes errors making the transformation of the sense coil voltages to transfer power appear invariant to misalignment. Sense coil positions and radii are optimized using penalty functions. Numerical models from precise theory confirm the fidelity of the approximation and experimental results concur. The results on experiments are better than the most stringent $\pm$0.2% standard (ANSI C12.20-Class.2). The error is decreased by five times than the results in previous research which used only two sense coils.

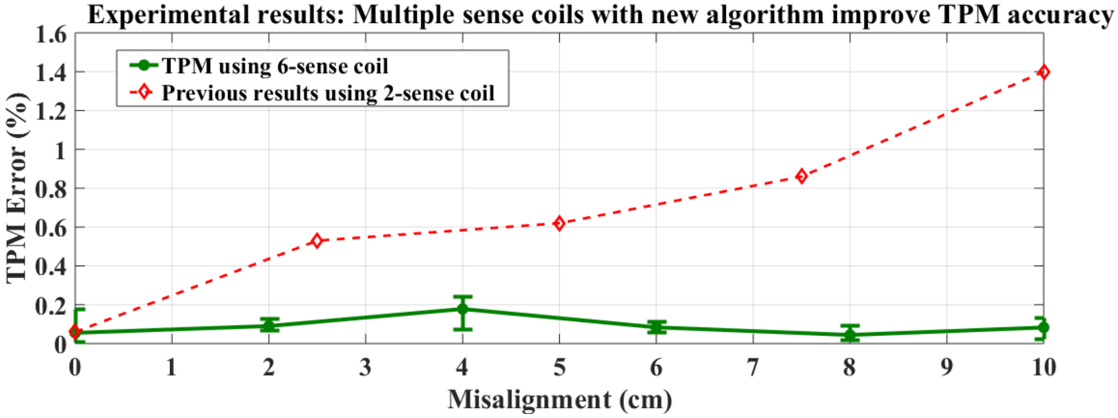

Results from the numerical model




Experimental setup




Experimental results: Multiple sense coils with new algorithm improve TPM accuracy



# Iron Sulfide Supraparticles as Artificial Viruses for Gene and Gene Editing Therapies (AGSR_42)

**Emine S. Turali-Emre[1,2], Ahmet E. Emre[1,2], Nicholas A. Kotov[1,2,3,4,5]**

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Gene and gene editing therapies have been widely investigated for treatment of inherited or acquired genetic diseases. Efficient delivery of therapeutic agents has become a significant barrier in clinical applications due to the toxicity and instability of the vectors in the complex intracellular environment. Among non-viral vectors, inorganic nanoparticles (NPs) have become a popular strategy for nucleic acid delivery. Even though, NPs can condense the nucleic acids, the nanoshell geometry of viruses is advantageous for the gene/gene editing therapies cargo protection. Therefore, we synthetized iron-based inorganic nanoparticles which self-assemble into supraparticles with nanoshell geometry. We synthetized L-cysteine stabilized iron sulfide NPs in aqueous media to eliminate toxic reagents during synthesis. Careful selection of the reaction conditions such as precursor concentrations, pH level and reaction time allowed us to find a condition where iron sulfide NPs self-assembly into virus-like supraparticles. Transmission electron microscopy (TEM), TEM tomography and dynamic light scattering (DLS) were used to characterize these supraparticles for size, shape, and charge. Our results indicate that virus-like supraparticles contain continuous compartments, are positively charged (25±7.2 mV) and 74±21 nm in diameter. We loaded deoxyribonucleic acid (DNA) in the compartments during the formation of supraparticles. We tested these complexes in circular dichroism, UV-Vis spectroscopy, electrophoretic mobility shift and protection assays to confirm the encapsulation of DNA in the compartments. Since iron sulfide is a natural material, it presumably has low cytotoxicity and high biocompatibility. Supraparticles can condense DNA, protect it against degradation, penetrate through cellular membranes and facilitate endolysosomal escape in gene therapy. Therefore, development of these virus-like particles can be used as an effective cargo delivery tool for gene and gene editing therapies such as CRISPR.

# Transition to Turbulence Prediction over Aerospace Configurations (AGSR_43)


## Gustavo L. O. Halila, Krzysztof J. Fidkowski, Joaquim R. R. A. Martins

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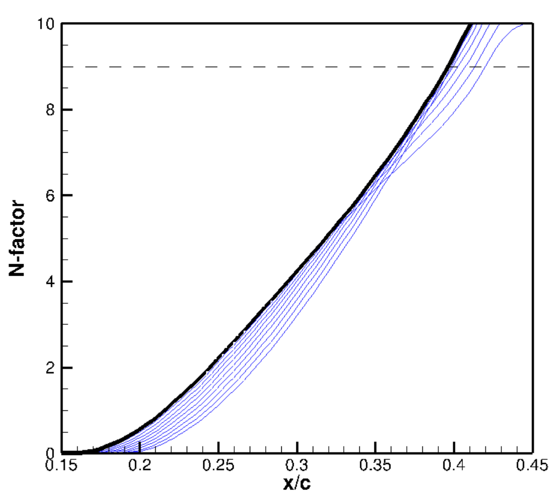
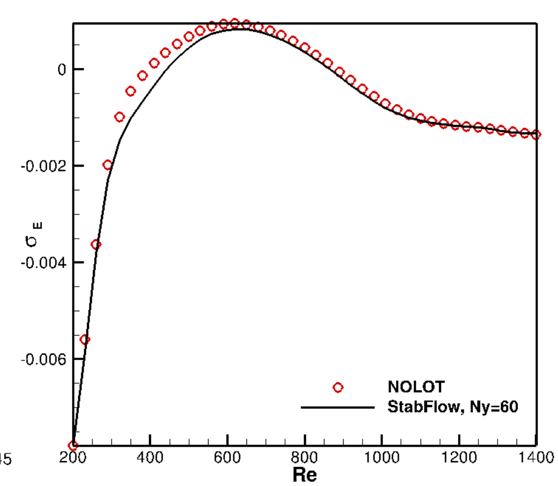
With the concern regarding green house effects and increasing oil prices, drag reduction in aircraft is a major target in the design process. Drag reduction can be achieved by extending the laminar region over the airframe, since laminar and turbulent boundary layer exhibit distinct behaviors and the latter presents a higher viscous drag than the former. During cruise flight conditions, more than half of the total drag in typical jetliners comes from viscous effects and, therefore, laminar flows are currently under investigation aiming at fuel savings.

In order to capture transition to turbulence in aerospace configurations, additional tools must be added to the Reynolds-Averaged Navier Stokes (RANS) models that serve as the basis for high-fidelity aerodynamic simulations over realistic geometries. Flow stability analysis tools investigate how a set of waves evolves in a given flow scenario, possibly leading to turbulence. For airplane aerodynamic analysis, two flow stability approaches are presently available: the Orr-Sommerfeld (OSE) method and the Parabolized Stability Equations (PSE). For aerodynamic flows over aircraft, the PSE is a well adapted tool since it considers convective flow instabilities that reproduce the behavior of the boundary layer dynamics.

In this work, we highlight the physics of transition to turbulence in fluid mechanics and show interesting examples of transition applied to airfoil flows. More specifically, we use a compressible, linear PSE implementation (called StabFlow) coupled to a boundary layer solver and a RANS CFD solver that, along with an $e^N$ method, allows us to predict aerodynamic flows that present both laminar and turbulent flow regions. Our method handles incompressible flows, and one example of transition prediction over a NACA0012 airfoil is seen in the figure on the left. Here, transition takes place at 39% of the chord. Compressible flows in transonic or supersonic regimes can also be assessed, as it can be seen in the figure on the right. In this figure, the energy-based amplification rate of a wave propagating over a flat plate in supersonic flow at a Mach number of M=1.6 is illustrated, and results of our implementation are compared to a benchmark code.

Future research interests include the use of StabFlow along with RANS CFD tools to perform aerodynamic shape optimization including transition to turbulence effects.



# Surface Morphology and Thermal Cleavages of Ultrafast Laser Irradiated β-$Ga_2O_3$ (AGSR_48)


## Minhyung Ahn[1], Alex Sarracino[2], Abdul Ansari[2], Ben Torralva[3], Steven Yalisove[4], Jamie Phillips[1]

*[1]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*
*[2]Applied Physics Program, University of Michigan, Ann Arbor, MI*
*[3]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI*
*[4]Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI*



The intrinsic properties of gallium oxide ($Ga_2O_3$) are highly favorable for transforming applications in power electronics, UV solar blind detection, and gas sensing. Ultrafast (femtosecond pulse) laser irradiation provides a unique means of material modification. In this work, ultrafast laser irradiation of single crystal (010) β-$Ga_2O_3$ (Sn-doped and unintentionally doped) will be presented. The β-$Ga_2O_3$ substrate was irradiated by a Ti:sapphire ultrafast laser (780 nm, 150 fs pulse width) with varying fluence and number of shots in air ambient. Single exposure irradiation above ablation threshold results in concentric modified regions with differing optical contrast, possibly indicating melting or a phase transition of the material. Threshold fluence for these regions were evaluated by plotting effective radius and laser fluence. Noticeably, a number of parallel features resembling cleavages are observed in single irradiation experiments. These features are aligned with a particular crystallographic direction in the β-$Ga_2O_3$ substrate and are independent of laser polarization. These features exhibit a second, less dominant, feature similar to a cleavage at roughly 90 degrees to this crystallographic direction. The more dominant features have a width of ~60 nm as measured by AFM while the less dominant features are smaller, measuring ~30 nm. These features are not commonly observed in ultrafast laser irradiated materials. Measurements of crystallinity of this surface region are presented. Several characterization techniques proved that there was no phase transition of ultrafast laser irradiated β-$Ga_2O_3$. Laser induced thermal stress is suggested as the origin of these features. Furthermore, for the fluence regime below ablation threshold, laser induced periodic surface structures (LIPSS) were observed by laser rastering and multi-shot irradiation of $Ga_2O_3$. The surface morphologies of these materials will be presented, characterized by laser confocal microscopy, scanning electron microscopy, and atomic force microscopy. Crystallographic information will be reported based on analysis by Raman spectroscopy, electron backscattering diffraction. These results will provide a preliminary understanding of ultrafast laser interaction with $Ga_2O_3$, and may offer a unique means for morphological and electronic modification of $Ga_2O_3$ relevant for device applications.

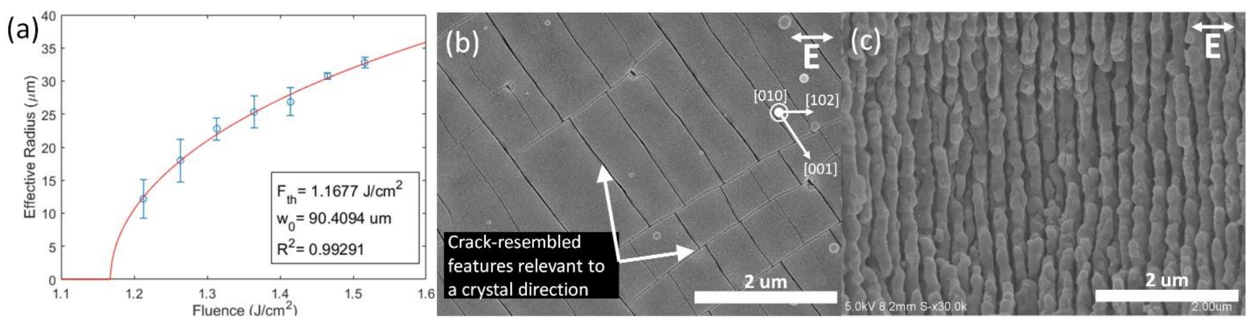




Figure. (a) Curve fitting of ablation threshold fluence of Ga2O3. (b) SEM image of cleavage features where the alignment is related to a crystal direction. (c) SEM image exhibiting high spatial frequency LIPSS (HSFL).

# Best Practices for Modeling Structural Boundary Conditions due to a Localized Fire (AGSR_50)


## Alyssa DeSimone, Ann E. Jeffers

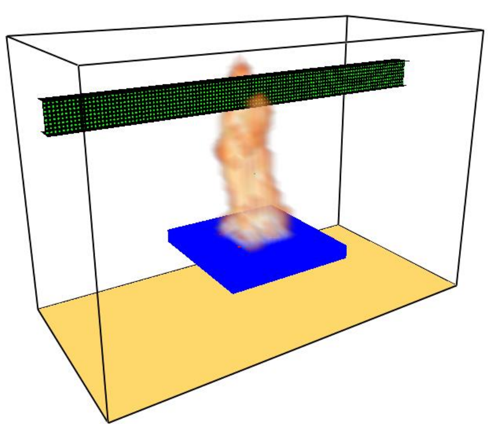
*Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI*


The standard fire exposure (e.g., ASTM 119) has come under criticism in recent years due to the fact that it does not capture many important features of natural fire exposure. In particular, it assumes that the gas temperatures surrounding a structural component (e.g., a beam) are uniform. Recent studies have shown that other fire models (e.g., localized fire) may produce structural responses that differ from those observed in standard fire tests. Due to these limitations, a number of researchers have made advances toward simulating natural fire effects in numerical models and in structural fire experiments. One approach that shows much promise is the coupled computational fluid dynamics-finite element (CFD-FE) modeling of structures in fire. This approach uses CFD to model the fire behavior and FE analyses to model the heat transfer through the structure and its mechanical response.

A survey of literature shows a number of inconsistencies in how the thermal boundary conditions are represented at the fire-structure interface, and a uniform methodology is needed so that analysts can gain consistency in their results. In this study, a coupled CFD-FE analysis is used with various boundary condition assumptions to show the impact that the modeling assumptions can have on the prediction of the structural response. The boundary condition assumptions are compared and evaluated based on accuracy and computational expense.

This study considers two localized fire scenarios: (1) a square hollow section column subjected to an adjacent burner fire and (2) a steel I-beam subjected to a pool fire at mid-span. Figure 1 shows the CFD simulation and a selection of results from the analysis of Case 2. Figure 1 demonstrates that excellent agreement with experiments can be obtained when the boundary conditions are properly modeled. Displacement calculations, which were also part of the study, further demonstrate the importance of accuracy in the temperature calculations.

The study shows that the treatment of boundary conditions in CFD-FE models is not trivial. A wide range of structural temperatures can be obtained depending on the assumptions that are used in the heat transfer model. Given that CFD-FE models are becoming increasingly common in structural fire engineering, it is important that structural fire engineers are aware of the implications of modeling assumptions at the fire-structure interface.



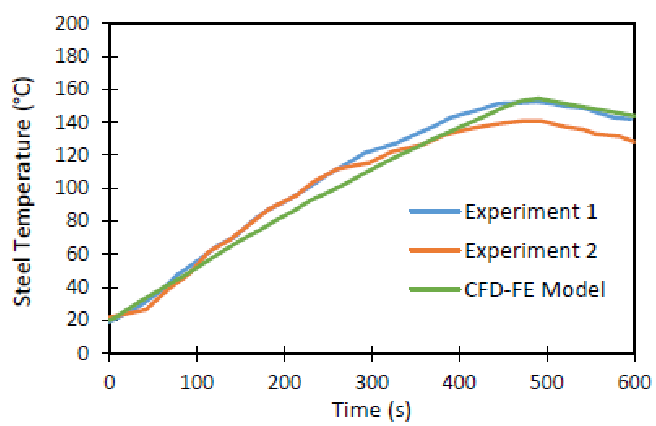



**Figure 1. Temperature development of an I-beam subjected to a pool fire at mid-span**

# Digital Control of a Multi-Megahertz Variable-Frequency Boost Converter for Dynamic LiDAR (AGSR_51)


## Xiaofan Cui, Al-Thaddeus Avestruz

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


The LiDAR(Light Detection and Ranging) sensor is widely used as the “eyes” of autonomous ground and airborne vehicles because of its high accuracy in long-range detection and low sensitivity to ambient interference. The system efficiency and thermal dissipation of LiDAR can be significantly improved by dynamically adjusting parameters such as the number of active laser diodes and repetition rate with the vehicle speed and environmental conditions. A boost converter is usually used for creating a high voltage to the LiDAR transmitter. To support the rapidly fluctuating voltage level and power consumption demand of the dynamic LiDAR transmitter, the boost converter needs a fast dynamic response and large control bandwidth over a wide output voltage and load range. The dynamics of power converters vary with operating point and real-time tuning can be easily realized on a digital controller to ensure consistently good dynamic performance, in contrast to a single analog compensation network.

A boost converter with multi-megahertz variable switching frequency is a good candidate for dynamic voltage scaling (DVS) in dynamic LiDAR. However, the digital controller design strategies have been especially limited in this type of power converters. Either a high-cost ADC (analog-to-digital converter) or architecturally intensive control methods are required. In previous paper, we published a high-speed digital control framework with high accuracy and low sampling and computational burden. This control framework relies on the switching-synchronized sampled-state space (5S) that includes a series of non-periodic sampling and control actions, which are triggered by events instead of clocks.

In this paper, we theoretically verify the effectiveness of using this 5S based controller design method for a current-mode boost converter with constant off-time. We demonstrate a converter prototype in Fig. 1(a) that operates in CCM (Continuous Conduction Mode) with a peak switching frequency of 3.3 MHz. It can deliver 16 W of power from a 12 V vehicle battery to a 40 V LiDAR transmitter array. The experimental waveform corresponds to theory. A dynamic voltage scaling sequence of 20 V → 25 V → 30 V → 35 V → 40 V shown in the Fig.1(b) demonstrates stability of the closed-loop system over a wide operating range. The converter illustrates a fast rise time of approximately 5 μs with small overshoot in each voltage step.

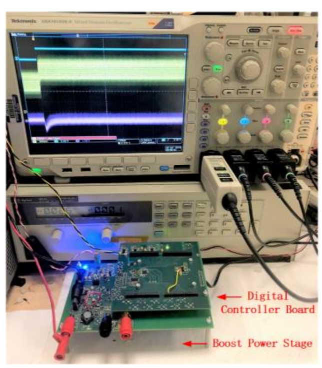



*Fig. 1 (a)*

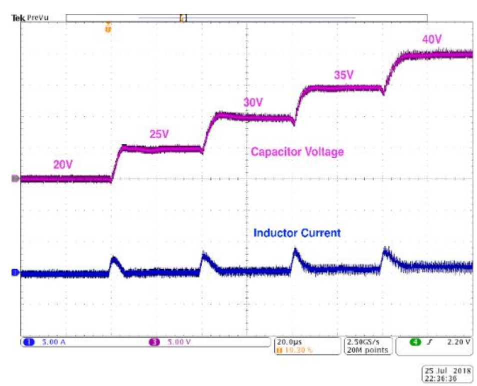



*Fig. 1 (b)*

## Hybrid Supraparticles for Protein Encapsulation (AGSR_52)

**Naomi S. Ramesar[1], Gleiciani de Q. Silveira[1], Trung D. Nguyen[1], Joong H. Bahng[2], Sharon C. Glotzer[1,3,4], Nicholas A. Kotov[1,2,3,4]**

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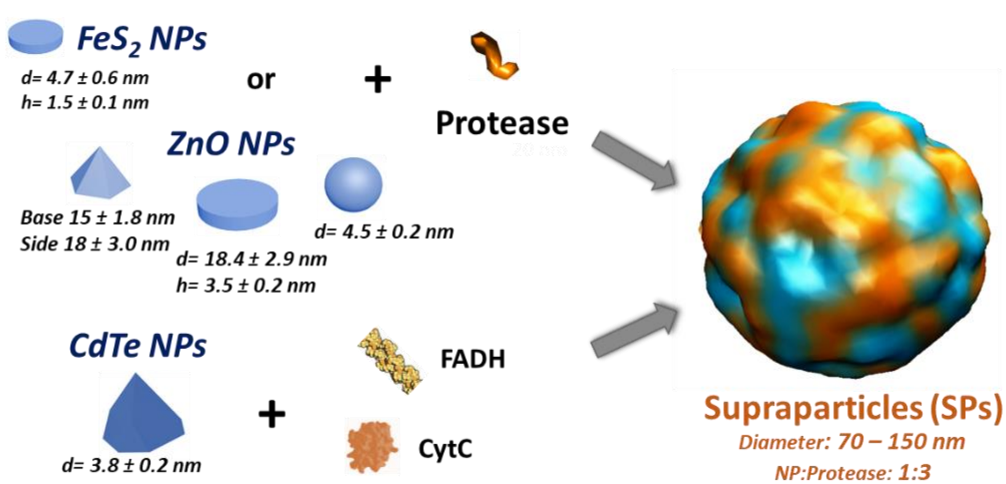
Enzymes are potent catalysts with high selectivity and specificity but are subject to instability due to temperature, hydrolytic activity by other enzymes, and reactive oxygen species. These drawbacks severely impede their utilization leading to a need for facile and effective immobilization techniques. Advancement in the synthesis of nanoparticles (NPs) with tunable size, controlled shape, and surface functionalization provides an excellent support for proteins. In this work hybrid supraparticles (SPs), self-assembled superstructures composed of proteins and inorganic nanoparticles, are formed as a tool for the encapsulation and immobilization of proteins, successfully separating them from the environments. SPs are formed by counterbalancing the underlying electrostatic repulsion and attractive interactions of proteins and NPs in the system. Here we show the spontaneous formation of five variations of hybrid SPs, self-assembled from proteins and NPs of various shapes. Iron disulfide ($FeS_2$) NPs stabilized with thioglycolic acid (TGA), and zinc oxide (ZnO) NPs of various shapes (plates, spheres, and pyramids) were combined with protease while, cadmium telluride (CdTe) NPs stabilized with 2-(dimethylamino) ethanethiol (DMAET) was assembled with two proteins, cytochrome C (CytC) and formate dehydrogenase (FADH). A prominent feature of this work is to highlight the versatility of forming hybrid SPs, their stability in various environments, and potential application as a new class of nano-tools for a range of applications, specifically encapsulation. Experimental results show iron disulfide SPs are capable of encapsulating and releasing protein with no change in enzymatic activity. The properties of these newly fabricated SP assemblies make them an attractive tool to potentially aid in the development and understanding of complex biological systems.



## Gamma-Ray Tracking for High Energy Gamma-Ray Imaging in Pixelated CdZnTe (AGSR_54)

### Daniel Shy, Zhong He

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Sequencing gamma-ray interactions within a detector system is an integral component of Compton imaging. In detectors with poor timing resolution compared to the time interval of successive interactions, algorithms which order gamma-ray interactions must be implemented using only energy and position information. This work examines previous algorithms and inspects interaction kinematics to increase the sequencing algorithm's speed and effectiveness. The proposed method, in which the first interaction is assumed to deposit the largest energy, has improved sequencing performance by greater than 20\% for full energy gamma ray depositions larger than 1 MeV with decreased computational cost in sequence reconstruction for events that do not contain pair-production. Experimental results show an almost twofold increase in the signal to noise ratio (SNR) for simple backprojection images of a Na22 source. Additional measurements of the 2.2 MeV gamma ray from H1(n,\gamma)D2 neutron capture shows the proposed algorithm's superior performance.

# Relative Contributions of Kupffer Cells and Liver Sinusoidal Endothelial Cells to Nanoparticle-Induced Antigen-Specific Immune Tolerance (AGSR_57)

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Biodegradable nanoparticles (NPs) have demonstrated their therapeutic potential to induce antigen (Ag)-specific immunological tolerance in autoimmune and allergy models. These peptide-containing poly(lactide-co-glycolide) (PLG) particles specifically suppress disease-associated T cells while preserving T cells necessary for protective immunity. Previous studies have implicated the spleen as the mediator of this tolerance; however, NPs induce tolerance in splenectomized animals. Additionally, most NPs administered intravenously accumulate in the liver. This study investigated the antigen presenting cells (APCs) of the liver, namely the Kupffer cells (KCs) and liver sinusoidal cells (LSECs), and their role in Ag-specific immune tolerance. Fluorescently labeled NPs associated with both cell types, but KCs scavenged more particles per cell compared to LSECs. Phenotypical analysis of these cells showed that co-stimulatory molecules CD80 and CD86 (involved in immune activation) were unaltered, but co-inhibitory molecule PD-L1 (involved in tolerance) was upregulated. Investigation of T cell responses showed that both KCs and LSECs are capable of T cell activation and induced regulatory T cells, a phenotype that actively induces tolerance. The roles of KCs and LSECs in regulating immunity was studied in a mouse model of multiple sclerosis, experimental autoimmune encephalomyelitis (EAE). The role of the liver was isolated by splenectomizing individuals, and the contribution of LSECs was isolated by specifically depleting KCs with clodronate liposomes. KC depletion did not prevent immune tolerance by NP infusion indicating that KCs may not be required for NP-induced tolerance. Together, these results demonstrate the role of the liver in particle-induced tolerance and highlights the sufficiency of LSECs for this systemic tolerance.

## An Efficient Framework for the Inelastic Performance Assessment of Wind-Excited Structural Systems (AGSR_59)


### Wei-Chu Chuang, Seymour M.J. Spence

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



The modeling and estimation of the inelastic response of wind-excited structures has assumed a great importance with the introduction of performance-based wind engineering. The long duration of typical wind storms makes the estimation of extreme responses computationally challenging. This is further complicated if it is recognized that uncertainties must also be propagated through the system. In this work, a computationally tractable method is developed to address this issue. The approach is based on the theory of dynamic shakedown which is capable of efficiently determining the safety of structures against low cycle fatigue and incremental plastic collapse. The plastic strains and deformations associated with occurrence of the state of shakedown are further estimated through a path-following algorithm. In particular, distributed plasticity is considered through a fiber-based finite element formulation, therefore allowing a complete description of plasticity along the member length. The efficiency with which this information can be estimated for any given wind load time history enables the development of a simulation-based framework for the estimation of the system-level inelastic probabilistic performance of the structure. The practicality and potential of the proposed framework is illustrated on a large-scale case study.

# A Multi-Objective Optimal Structural Design Framework for Wind-Excited Uncertain and Dynamic Building Systems (AGSR_60)


## Arthriya Suksuwan, Seymour M.J. Spence

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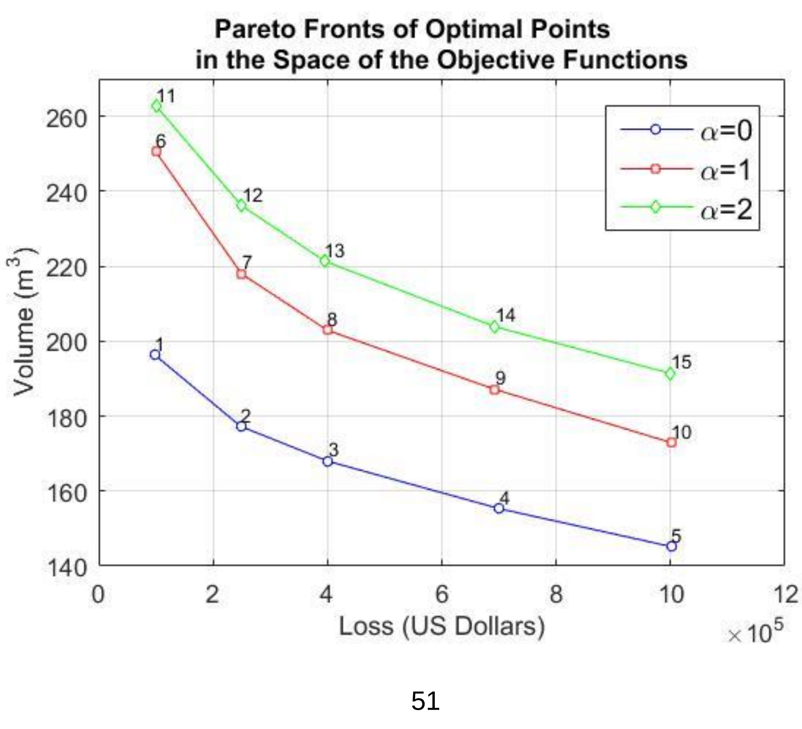
The major challenge in designing wind-sensitive structural systems in hurricane-prone areas is the identification of the optimal compromise between the upfront construction cost and risk mitigation. To provide decision-makers with a set of cost-effective trade-off solutions, this research proposes a framework for identifying structural designs that simultaneously optimize initial cost of the system and the anticipated losses caused by an extreme wind hazard. For wind-excited uncertain and dynamic systems, solving this multi-objective design optimization involves not only a large number of design variables in the optimization process, but also a large number of random variables necessary to properly model stochastic wind loads and system uncertainties in the loss assessment. Hence, this type of engineering problem generally requires a significant computational effort. To overcome the computational burden, the proposed framework first reformulates the multi-objective optimization problem into a suite of single-objective optimization problems by transforming all but one objective function into constraint functions. Each single-objective optimization problem is then transformed into a sequence of approximate optimization sub-problems. In particular, each sub-problem is defined in terms of kriging metamodels and auxiliary variable vectors, which are calibrated from results of a single loss assessment carried out in a fixed design point. Based on this formulation, the sub-problems can be efficiently solved by any gradient-based deterministic optimization algorithms. Sub-problems are solved sequentially until two consecutive solutions are identical, ensuring an exact solution to the single-objective optimization problem. Once all single-objective optimization problems are solved, the solutions are obtained that constitute the Pareto-optimal solution set of the original multi-objective design optimization problem. The applicability and the efficiency of the proposed framework is demonstrated through the design of a 37-story building system, where a set of trade-off solutions are identified that simultaneously optimize the total volume of structural material and the system-level loss measure defined in terms of expectation and standard deviation of the total repair cost associated with wind-induced damages.

## Quantum Theory for Local Excitations in Semiconductor Nanostructures (AGSR_61)

**Markus Borsch[1], Eric W. Martin[2], Steven T. Cundiff[2,1], Mackillo Kira[1,2]**

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[2]*Department of Physics, University of Michigan, Ann Arbor, MI*

The ongoing miniaturization of electronic and optoelectronic devices can reveal the quantum nature of matter and lead to deviations from classical behavior. At the same time, the extraordinary properties of excitons (for example their large absorbance) can be directly utilized in optoelectronic devices. Any systematic design of such nanostructure devices requires a detailed description of the fundamental quantum processes including formation, interaction, and transport of carriers, excitons, and other quasiparticles. We present a new microscopic theory that extends established theories to describe homogeneous excitations of semiconductors (the semiconductor Bloch equations), to also include spatial inhomogeneities that occur in semiconductor nanostructures.

As a proof of principle, we apply it to study an experiment where a gallium arsenide quantum-well sample is excited by an ultrafast and tightly focused laser pulse. A second time delayed pulse that is also scanned across the optically excited region is used to study the excitation dynamics with spatial and temporal resolution. Figure 1 shows the change of the excitation spot size as a function of time that can be extracted from the measurement. An unexpected transient decrease of the spot size by about 2% can be observed, before the dynamics transitions into a diffusive expansion. Our theory quantitatively explains this phenomenon and identifies that the effect stems from the conversion of polarization to incoherent excitons as well as excitation induced shifts in the system. As an outlook, our new approach can be extended to study localized quantum optoelectronic excitations in semiconductor nanostructures.

In conclusion, we have developed a new approach to describe spatially localized excitations in semiconductor nanostructures and applied it successfully to explain the surprising experimental observation of a narrowing excitation spot size.

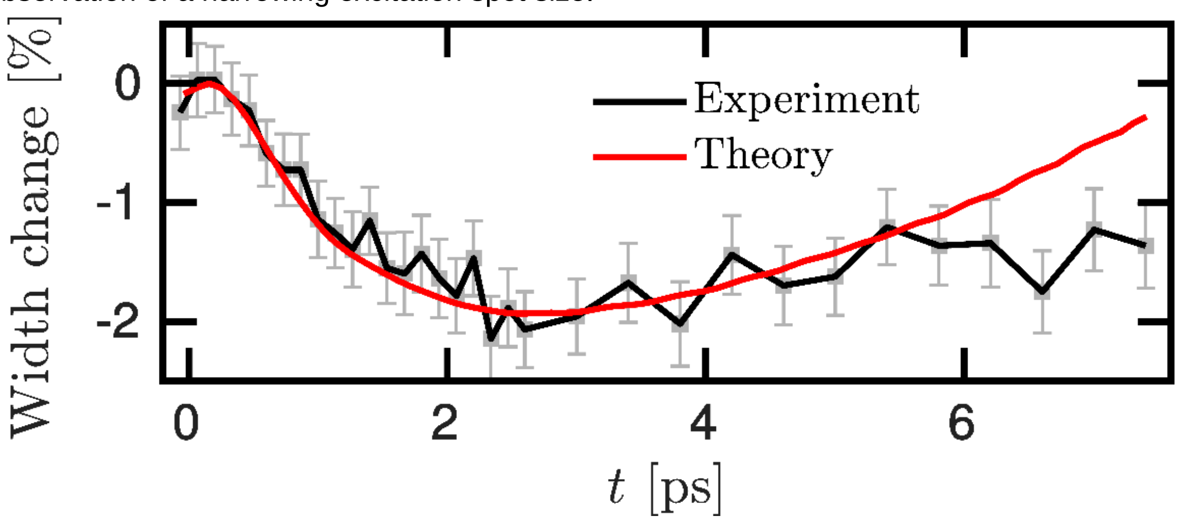


**Figure 2**: Change of excitation spot width after local excitation of a GaAs quantum well sample with a 600 nm wide pump spot. Theoretical calculation in red, experimental measurement in black with error bars.

# Data-driven Sequential Decision Making under Data Uncertainty and Model Ambiguity with Applications to Medical Decision Making (AGSR_62)

## Lauren N. Steimle[1], Brian T. Denton[1,2]

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Optimization models have long been used to transform data into optimal decisions. However, limitations in the input data for optimization models can cause the resulting recommendations to underperform in practice. In this work, we address the limitations of optimization models for stochastic systems that arise from imprecise input data or lack of consensus on model assumptions. We created a new data-driven optimization framework that allows for the optimization of decisions with respect to multiple models of the stochastic system and results in recommendations that are more resilient to errors in the data and assumptions.

Our work is motivated by the need for these approaches to optimize personalized treatment strategies for cardiovascular disease (CVD), the leading cause of death in many countries. With the help of our collaborators at Mayo Clinic and the United States Department of Veterans Affairs, we have modeled CVD as a Markov decision process (MDP) in which a decision-maker (DM) can influence the stochastic evolution of the disease by intervening with medications. Standard optimization methods can be used to optimize the timing and sequencing of medications with the goal of delaying the onset of major adverse events such as heart attacks and strokes, assuming the stochastic model is an accurate representation of CVD progression. Unfortunately, the optimal strategy recommended by MDPs is sensitive to the data and assumptions used to create the model, which are subject to error and ambiguity in practice. For example, the evolution of disease is typically estimated from observational data but limited sample sizes for various treatment regimens can lead to statistical uncertainty, and there may be scholarly disagreement regarding the best evidence from clinical studies to estimate a patient's risk of adverse events based on physiological and demographic risk factors.

To account for data uncertainty and model ambiguity, we created a new optimization approach, called the Multi-model MDP (MMDP), which generalizes an MDP to incorporate multiple models of the system. We characterize two variants of this problem depending on the strategies available to the DM: static (adaptive) strategies that are independent (dependent) of the realizations of the parameters. We show that these problems are NP-hard and PSPACE-hard, respectively. Connections to stochastic programming and partially-observable MDPs give rise to exact solution methods for both problems and we show empirically that learning strategies provide little benefit over the static strategies, which are typically more desirable, especially in medical applications where random exploration may not be accepted. To solve the static problem, we created a mixed-integer linear program; however, this formulation is challenging to solve due to the inclusion of binary decision variables and the introduction of logic-based constraints. By leveraging problem structure, we have been able to design exact algorithms that solve problem instances that were unsolvable using more traditional decomposition methods, such as Benders decomposition, and designed a fast approximation algorithm with error bounds. As a result, we have been able to design policies that are less sensitive to errors in the data. In the context of CVD, we showed that the MMDP framework can help resolve disagreements about well-established but conflicting clinical studies of cardiovascular disease. Our results can generalize to many other settings, beyond medical decision-making, such as those arising in inventory control, finance, and energy systems.

# Confined in Flatlands: Coulomb Interaction in 2D Materials (AGSR_64)

**B. Girodias[1,2], M. Kira[2]**

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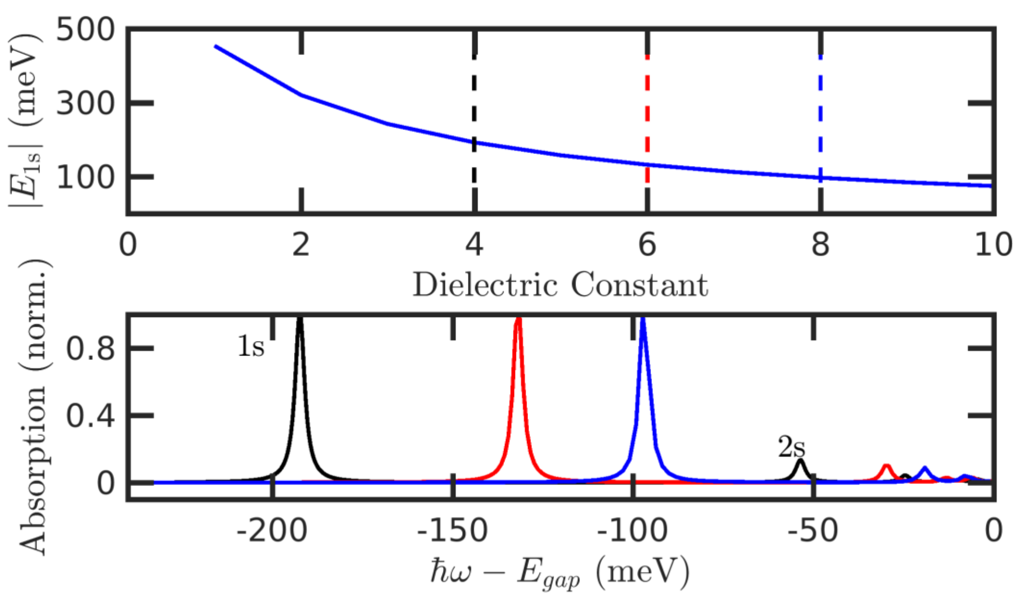
Atomically thin two-dimensional (2D) materials are intriguing quantum materials because their properties are often dominated by quantum effects even at room temperature. For example, Transition Metal Dichalcogenides (TMDCs) have such strong many-body effects that they exhibit discrete exciton resonances stemming from Coulomb-bound electrons and holes at room temperature. Additionally, their electronic spin can be externally controlled and detected by optical fields, which could be the basis of optoelectronic qubits – the smallest elements of quantum information.

In this study, we will systematically study Coulomb interaction between charges to calculate the optical absorption of 2D materials, including the effect of environment surrounding TMDCs. Technically, we use an exact set of semiconductor Bloch equations (SBEs) to compute the optical response. Fundamentally, the SBEs are based on the quantum dynamic cluster-expansion approach that systematically describes the strictly sequential build up of simple to highly correlated N-particle quantities. The SBEs are then numerically solved, producing new insight by varying the parameters of interest.

Figure 1 shows the computed exciton binding energy (upper) and absorption spectra (lower) as a function of the dielectric constant of the surrounding materials. The strength of exciton binding strongly decreases with increasing dielectric constant. In actual experiments, decreasing exciton binding is largely compensated by a band-gap ($E_{gap}$) shift, making strength of Coulomb effects less visible in measurements. To resolve this, we show that the Coulomb binding can be directly detected when excitons are accelerated with strong electromagnetic fields. In summary, we show that Colombic effects of 2D material can be controlled by environment and detected directly via strong-field spectroscopy.




(upper) $E_{1s}$, the binding energy, as a function of the dielectric constant.
(lower) The optical response for different environments. Here the gap energy is held constant.

## Neglecting Future Urban Development and Dynamic Risk Can Lead to Maladaptation to Natural Hazards (AGSR_66)

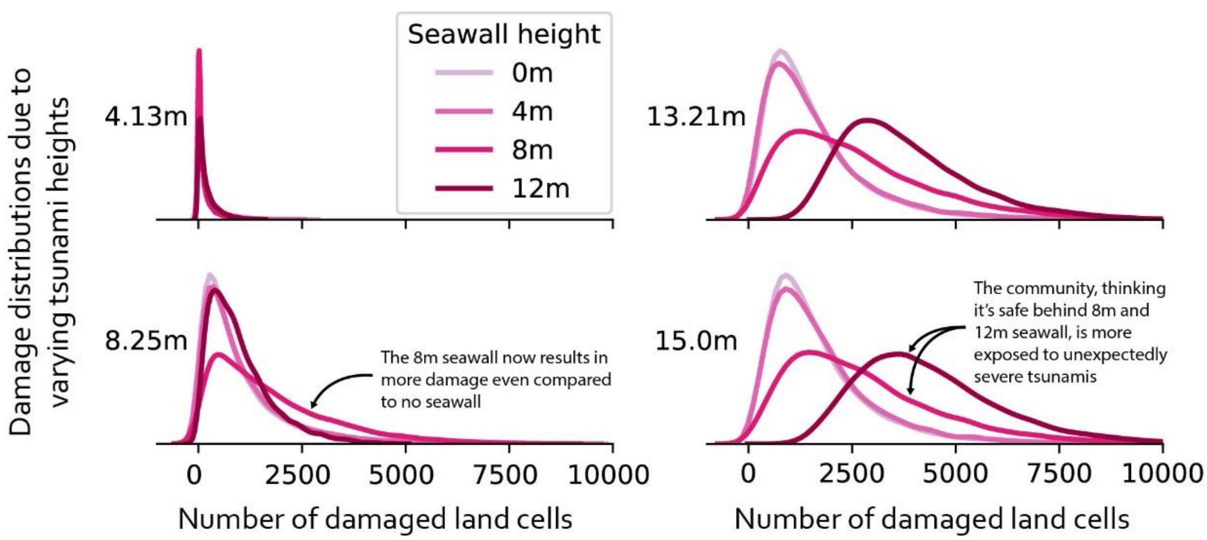
**Tom Logan, Seth Guikema**

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

By the time you read this, Hurricane Florence will have caused major damage along the East Coast of the USA. This is the latest in a string of disasters that highlight the inadequate integration of risk analysis and urban planning. A major challenge for mitigating natural hazards and adapting to climate change is in determining what action is necessary. The existing approach favors hard-adaptative measures such as seawalls and levees. However, this raises the potential for maladaptation, wherein the adaptive measures inadvertently increase the vulnerability of the communities they're supposed to protect. In this work we model the effect of changing risk and community awareness of hazards on the urban planning process to address this question.

In particular, we develop a coupled stochastic model that includes tsunami hazard, urban development, and decisions regarding adaptative strategies. We represent the growth of a small town in North-Eastern Japan using a cellular automaton model. Over the course of 300 simulated years the town is threatened by tsunami of varying magnitudes. The town can build a seawall along its coast in an attempt to defend itself. Our results show, in contrast to prevailing thought, that larger seawalls can in fact increase the damage to a community from large tsunamis (figure below). In these scenarios the increased vulnerability is due to the false sense of security provided by the seawall. This causes development to occur in zones that remain at risk from extreme tsunami.

The key result, for the natural hazard and climate impact community, is that neglecting future urban development and adaptation in the risk analysis can produce results that support maladaptive actions. Although we demonstrate this in the case of tsunamis, this notion may be generalizable to other spatial and repeatable hazards such as flooding, wild fires, and storm surge. This has major implications for how future risk assessment is conducted to inform our communities' adaptation and provides a necessary step towards integrating risk into urban planning.



# Effect of Crosslinking of Ovalbumin Nanoparticles on Cellular and Humoral Immune Responses (AGSR_68)


**Nahal Habibi[1, 5], Stephanie Christau[1, 5], Lukasz Ochyl[6], James J. Moon[3,6], Joerg Lahann[1,2,3,4,5]**

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Cancer immunotherapy takes advantage of the body's own immune system to fight cancer. Antigen-specific immunotherapy is realized by identification of cancer-specific antigens. Those antigens can be delivered to dendritic cells (DCs), which can initiate an immune response against the tumor by processing and presenting captured antigens to T cells.

"Next-generation" vaccines or subunit vaccines are based on recombinant proteins or naked DNA; despite great promises, poor immunogenicity remains a big challenge. This issue can be addressed by using nanoparticles for co-delivery of the antigens and an adjuvant, which enhances the immune response.

Previously, antigens were loaded into particles or conjugated onto their surface. However, the delivery of antigens via a particle carrier requires either degradation of the particle to release the antigen, or post-modification of the particle surface for antigen conjugation. Both may result in insufficient antigen delivery. We address this issue by fabricating nanoparticles that are made of the protein antigen itself. By using electrohydrodynamic co-jetting, monodisperse nanoparticles made entirely from model protein antigen ovalbumin (OVA) are fabricated. Specifically, we fabricate OVA nanoparticles with 3 different crosslinker densities and two different sizes (200 nm and 500 nm). We find that DCs readily internalize and process the OVA particles, and OVA particle-treated DCs result in proliferation of cytotoxic T cells. Both, crosslinker density and size, are shown to affect the proliferation of T cells.

# Non-Equiprobable Statistical Analysis of Misfires and Partial Burns for Cycle-to-Cycle Control of Combustion Variability (AGSR_71)


## Bryan Maldonado, Anna Stefanopoulou

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



Cycle-to-cycle combustion variability (CV) in spark ignition internal combustion engines is amplified at high levels of exhaust gas recirculation (EGR) by sporadic partial burn and misfire events. A new methodology is proposed for understanding the cycle-to-cycle variability of the combustion process at the tipping point where high EGR levels suddenly trigger sporadic misfires. The indicated mean effective pressure (IMEP) was used as the cyclic parameter for categorizing combustion cycles into 1) high energy, 2) nominal, 3) partial burns, and 4) misfires. Thresholds for IMEP based on return maps are suggested for cycle classification. Deterministic patterns mainly involved misfires followed by high energy cycles due to the extra oxygen and fuel present at the intake stroke inside the cylinder immediately after a misfire. However, this study suggests that previous cycles do not have a major influence on the occurrence of misfires and partial burns, making them random in nature. On the other hand, this study shows that the occurrence of partial burn and misfire cycles is the product of the stochastic component of cyclic CV with statistical properties similar to a multinomial probability distribution. It is demonstrated that observation of partial burns can increase the probability of observing a misfire when the conditional probability is used as the metric. Based on these findings, future work will be able to use the observation of partial burns alone to control the upper bound on the probability of misfire events. To this end, different metrics are proposed to control directly and indirectly the probability of misfires, and their advantages and disadvantages for feedback combustion control are discussed.

# Trajectory Optimization of a Supersonic Aircraft Considering Thermal Loads (AGSR_74)

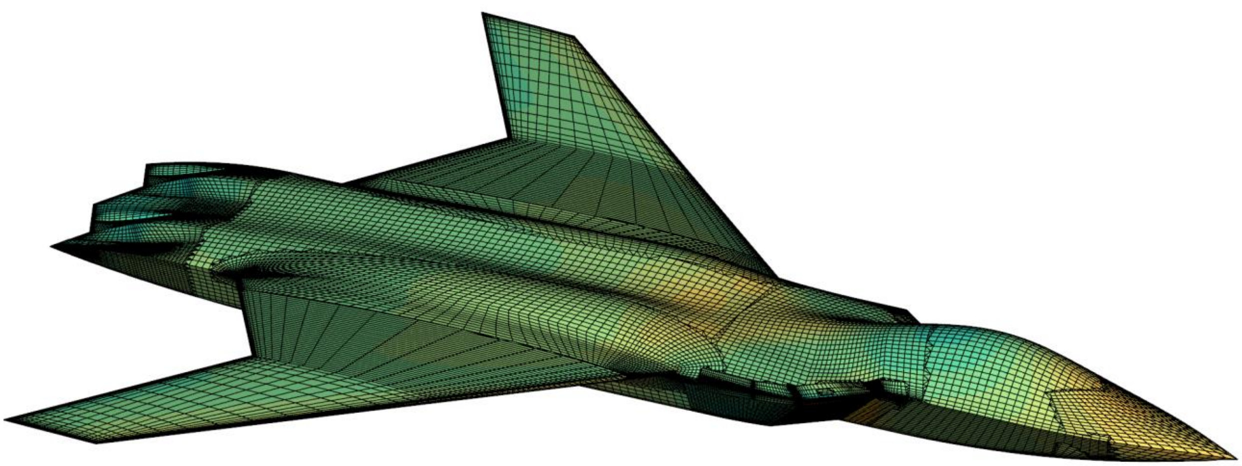

## John P. Jasa, Joaquim R. R. A. Martins

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


An aircraft's ability to dissipate heat can have a large impact on its performance. As the complexity and energy usage of next generation aircraft's avionics systems and electrical loads increase, we need to consider thermal effects earlier in the aircraft design process to avoid performance degradation. To do this, we need to consider the interactions between the aerodynamic, propulsive, and thermal systems.

We aim to determine the optimal flight-path trajectory for a supersonic aircraft in a variety of situations, including when its heat loads are critical. Because the aircraft uses fuel to cool the aircraft, we expect that radically different flight paths may be optimal when considering the coupled relationship between fuel burn and ability to dissipate heat. We will analyze these trajectories using computational fluid dynamics (CFD), jet engine analysis, and trajectory integration software.

This work demonstrates a coupled aero-thermal-mission model which we use to optimize the trajectory of a supersonic aircraft subject to thermal constraints. We show that the optimal flight path depends on the effectiveness of the fuel thermal management system. Introducing a heat exchanger and recirculating warmed fuel back into the tank allowed the aircraft to complete the minimum time-to-climb problem 22 seconds faster than when using a non-recirculating system. We find that for a given heat loading, there exists a trade-off between increasing the thermal capacitance of the aircraft, recirculating fuel, and climbing at a different rate to minimize heat input to the system.



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## The Variation of Solar Wind Helium through Two Solar Cycles (AGSR_78)


### B. L. Alterman[1,2], Justin C. Kasper[2]

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We study the relationship between solar wind helium abundance ($A_{He}$) and sunspot number (SSN) over more than 22-years covering two full solar cycles. This is the first time the Wind spacecraft has measured the solar dipole returning to an orientation analogous to its orientation immediately following launch. Observations from the Wind spacecraft Faraday cups demonstrate a phase offset between $A_{He}$ and SSN. The study also updates previous results from 2007 and 2012 that demonstrated the strong correlation between $A_{He}$ and SSN, clearly showing that the sun is entering solar minimum 25.

# Joint Formation in Multi-layered Ultrasonic Welding of Ni-coated Cu and the Effect of Preheating (AGSR_79)


## Ying Luo[1], Haseung Chung[3], Wayne Cai[2], Teresa Rinker[2], Jeffrey Abell[2], E. Kannatey-Asibu[1], SJ. Hu[1]

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[2] *Manufacturing Systems Research Laboratory, General Motors R&D Center, Warren, MI*

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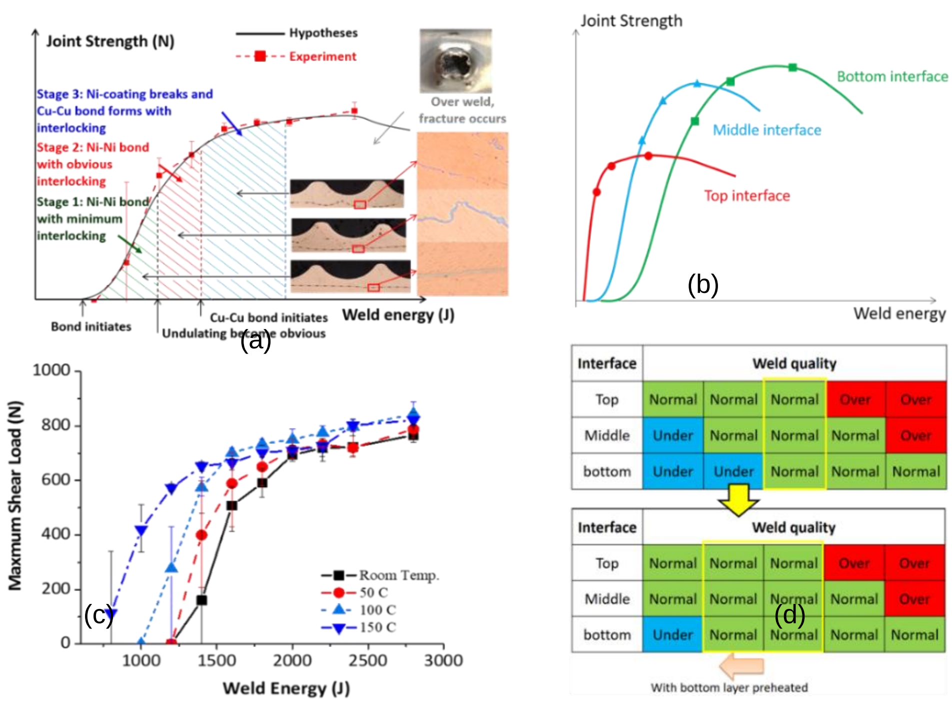
Multi-layered ultrasonic welding (USW) is widely used in joining of electrodes or tabs in lithium-ion batteries. To achieve quality joints and enhance the welding process robustness, an improved understanding of the joint formation is highly desirable. In this research , USW of 4-layered Ni-coated Cu is studied to investigate the joint formation at a single interface and joint propagation from interface to interface under both ambient and preheated conditions. The results indicate that joint formation involves three major mechanisms: Ni-Ni bonding with minimal mechanical interlocking, Ni-Ni bonding with moderate mechanical interlocking, and a combination of Ni-Ni bonding, Cu-Cu bonding, and severe mechanical interlocking. Results also show that joints propagate from the interface close to the sonotrode side to that close to the anvil side. It is further observed that the joint formation can be accelerated and the joint strength can be improved with process preheating, especially at the interface closest to the anvil. The effect of preheating is most significant during the early stage of the process, and diminishes as process progresses. The favorable effects of preheating improve the robustness of multi-layered USW


Results: (a) conceptual relationship between weld energy and joint strength during joint development; (b) joint formation at top, middle and bottom interfaces; (c) lap-shear results for preheated and non-preheated samples at bottom interface; (d) influence of interlocking on weldability of multi-layered USW.

# First-Principles-Based Transition Optimization of a Tilt-wing Electric Vertical Takeoff and Landing Aircraft (AGSR_80)


## Shamsheer S. Chauhan, Joaquim R. R. A. Martins

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



Electric vertical takeoff and landing (eVTOL) aircraft for urban mobility are currently receiving considerable attention due to their potential to change the way we move within and between cities. Although electric aircraft are not a new concept, improvements in technologies like batteries and autonomous control have made them significantly more feasible for short distance on-demand transportation. However, this sector of the aviation industry is still in its infancy and there is a lot of scope for development. In this work we focus on the trajectory of a distributed propulsion tilt-wing eVTOL aircraft. Optimizing the trajectory of a tilt-wing aircraft provides an interesting challenge because the transition from vertical to horizontal flight is a delicate balancing act in which the fans need to provide sufficient thrust to maintain lift and accelerate while transferring the burden of lift to the wings. Additionally, optimizing this phase is a unique design challenge because it requires considering states in which the flow over the wing is separated. We use gradient-based optimization methods and first-principles-based models to optimize the trajectory of a selected eVTOL aircraft configuration.

## A Distributed Simulation Platform to Probabilistically Quantify Hurricane Resilience of Communities (AGSR_82)


### Ahmed U. Abdelhady, Seymour M.J. Spence, Jason McCormick

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


The risk from natural hazards has been increasing over time with hurricanes one of the costliest natural hazards to impact the United States over the past four decades. Mitigation of the risk of natural hazards can be achieved through the concept of community resilience which is an essential requirement for the nation’s security and welfare. This research presents a framework to probabilistically quantify resilience of residential communities subjected to hurricanes. Resilience goals are defined, then quantifiable metrics are specified that can be directly compared to community resilience goals.

In order to quantify the resilience metrics, direct damage after the hurricane is calculated using a component-based vulnerability model. In particular, the vulnerability model integrates a parametric hurricane wind field model with a probabilistic debris trajectory model to calculate damage due to two mechanisms: excessive dynamic wind pressure and impact of windborne debris to the building envelope. Interdependencies induced between the two mechanisms are modeled using a distributed simulation platform. The platform uses Lightweight Communications and Marshalling (LCM) libraries to decouple the vulnerability model into three main simulators: hurricane simulator, debris simulator, and damage simulator. This decoupling makes the platform modifiable and extensible which implies that any replacement or update of any simulator can be carried out with minor effects on any other simulator.

Based on the level of damage of each building directly after the hurricane, a performance limit state is specified. Each of the performance limit states is directly related to a building recovery path. Building recovery paths are then aggregated to calculate the community recovery path. A Monte Carlo simulation engine has been implemented to evaluate the building and community recovery path probabilistically. A case study is presented for typical residential neighborhood subjected to a category three hurricane. The outcome is a probabilistic quantification of each specified resilience metric. This can help decision makers to compare current community resilience with target levels, identify the gap, and set strategies to improve community resilience.

# Grain Boundary Sliding and Slip Transmission Interaction in High-Purity Columnar Aluminum (AGSR_83)


## Marissa Linne[1], Ajey Venkataraman[2], Michael Sangid[2], Samantha Daly[3]

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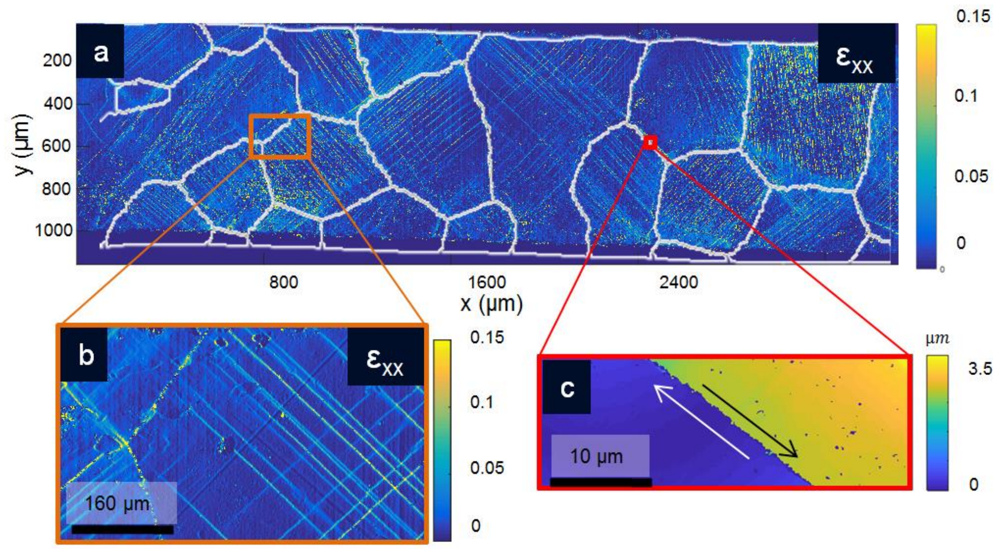
*[3]Department of Mechanical Engineering, University of California-Santa Barbara, Santa Barbara, CA*



Predictive modeling of structural metallic alloys, including the ability to tailor materials for energy-efficient use in advanced applications, is hindered by a limited understanding of the interactions between deformation mechanisms and microstructural features. Deformation mechanisms such as dislocation slip transmission and grain boundary sliding (GBS) are largely treated as independent events, irrespective of indications that they may be synergistic. Limited experimental data makes it difficult to accurately predict damage localization. In this work, new experimental approaches are used to characterize mechanism-mechanism relationships and the effect of local microstructure in columnar, high-purity aluminum. Using SEM digital image correlation (SEM-DIC) and electron backscatter diffraction, high-resolution displacement fields and grain orientations are captured and statistically analyzed to identify deformation trends with respect to local microstructure. An example of a resulting full-gage SEM-DIC measured strain field is shown in **(a)**, with inset **(b)** highlighting resolution of individual slip traces, and **(c)** showing relative displacement tangent to the grain boundary, which is used to quantify in-plane GBS magnitude. These high resolution DIC data sets enable measurement of relative contributions of grain boundary sliding and dislocation slip and how these contributions change with microstructural neighborhood. Results are integrated with a parallel crystal plasticity model (Sangid Group, Purdue) to improve predictions of damage-inducing strain localization, with the ultimate goal of improving the capability to develop materials with greater resistance to failure.

## A Two-Step Heuristic for the Multi-Node Replenishment Problem in the Fast Food Supply Chain (AGSR_84)


### Alejandro Vigo Camargo, Yavuz A. Bozer

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In 2010 the USDA reported that over $220 billion were being spent at fast food stores in the U.S. While this is a significant sector of the food supply chain, there is little work focused on this particular segment. A large percentage of the cost in a fast food supply chain comes from the replenishment of the stores (outbound logistics), so understanding the advantages and limitations of alternative delivery methods is critical to minimize the cost of the overall supply chain.

The objective of this project is to develop an optimization model to minimize the outbound logistics costs of the fast food supply chain, by minimizing the number of deliveries and trucks needed, while meeting service level requirements and capacity limitations. To this goal, we developed a two-step heuristic to solve the replenishment problem under a direct-shipment policy. The first step minimizes the number of deliveries needed for each store. The second step minimizes the number of trucks using the result from the first step as a constraint. To evaluate the performance of the heuristic, large instances were created with 350 stores and 10 time periods. Each instance has different capacities for the stores and trucks in order to create varying delivery intensities (i.e. average delivery per day). The problem was also formulated as a linear program and solved using CPLEX to benchmark the quality of the solutions obtained by the heuristic. We show that the heuristic was able to find a solution at least 98% faster than CPLEX on all instances, while finding the optimal solution only for medium and low delivery intensity instances (0.4 and 0.2 average deliveries per day respectively). For the high delivery intensity instance, the heuristic was able to find the optimal number of deliveries, but was 11% over the optimal number of trucks needed. These preliminary results show the potential this heuristic may have as a solution method for alternative delivery methods, such as pre-defined routes, fixed delivery schedules and milk runs.

# A Coarse-Grained Molecular Dynamics Model of Single-Stranded DNA-Functionalized, Shaped Nanoparticles (AGSR_86)

**Benjamin E. Swerdlow[1], Fang Lu[2], Matthew Spellings[3], Julia Dshemuchadse[3], Oleg Gang[2,4,5], Sharon C. Glotzer[1,3,6]**

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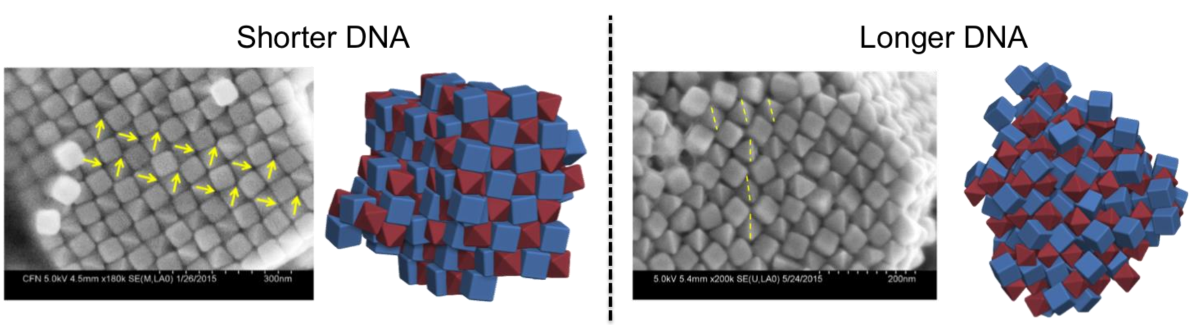
Typical materials science follows a top-down approach: processing conditions influence the formed structure, dictating the key material properties. Conventional processing often limits fine control over structure-property relationships. However, advances in nanotechnology, such as DNA nanoparticle (NP) functionalization, enable a bottom-up approach for materials design. By coating NP surfaces with DNA strands that terminate in unpaired bases, specifically engineered DNA sequencing can programmatically enforce NP bonding. Yet this enthalpic basis alone is insufficient to explain all aspects of DNA NP self-assembly: entropic parameters such as particle size and shape, as well as DNA flexibility and length, all contribute to the observed equilibrium structures. Computer simulations of these systems allow us to screen candidate building blocks and probe the effects of interactions between particles more easily and efficiently *via* computational rather than experimental exploration. Previously, a coarse-grained molecular dynamics model using the Discrete Element Method implemented in HOOMD-blue was used to simulate structures assembled in one-component double-stranded DNA (dsDNA) NP systems. Here we present an implementation to replicate experimental results for assembly of two-component flexible single-stranded DNA (ssDNA) NPs and to predict the unique assembly behavior of new binary systems of shapes. Our experimental studies on binary mixtures of DNA-coated shaped NP are in agreement with computational results. We find that both core NP shape and ssDNA flexibility are critical to self-assembly in these systems.



# Electromechanical Modeling and Experimental Verification of a Direct Write Nanocomposite (AGSR_87)


## Alireza Nafari[1], Henry A. Sodano[1,2]

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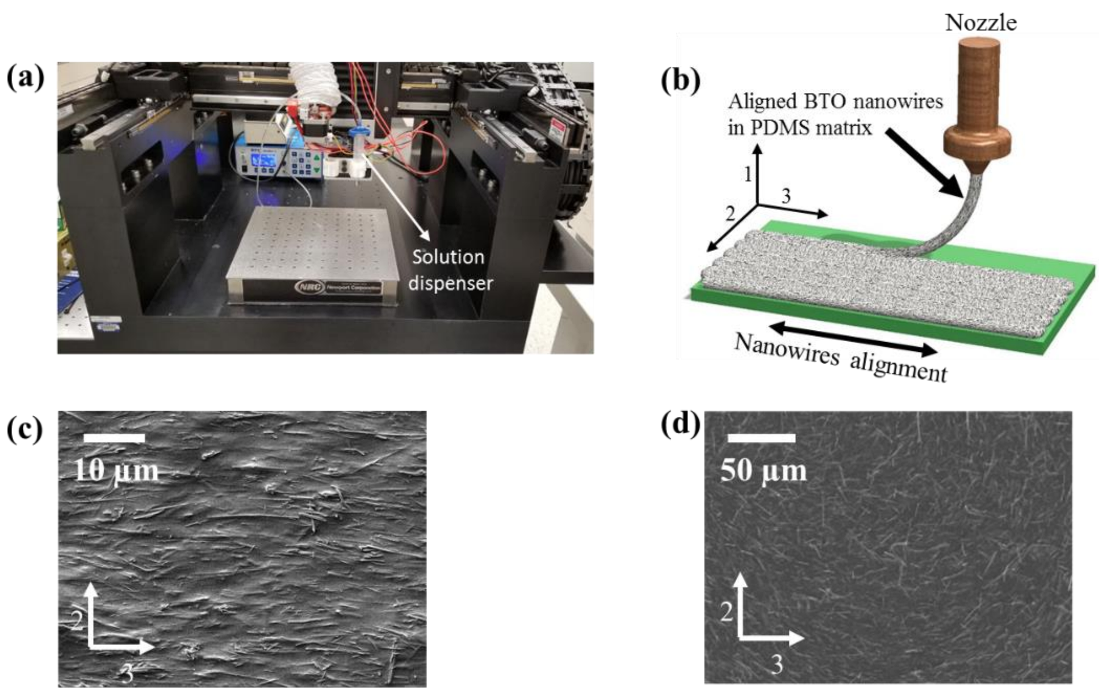
Piezoelectric materials are currently among the most promising building blocks for sensing, actuation and energy harvesting systems. However, these materials are limited in certain applications due to their lack of machinability as well as their inability to conform to curved surfaces. One method to mitigate this issue is through additive manufacturing (direct printing) of piezoelectric nanocomposites, where piezoelectric nanomaterials are embedded in a polymer matrix. Although significant progress has been made in this area, filler morphology, alignment and volume fraction are critical parameters that influence the electromechanical response and have not been adequately modeled. With the advent of additive manufacturing it is now possible to realize directly printed nanocomposites with tailored microstructure. The objective of this study is to develop and experimentally validate micromechanical and finite element models that allow the study of the electroelastic properties of a directly printed nanocomposite containing piezoelectric inclusions. Furthermore, the dependence of these properties on geometrical parameters such as aspect ratio and alignment of the active phase are investigated. In particular, the core focus of this work is to demonstrate how the gradual alignment of piezoelectric nanowires in the nanocomposite from randomly oriented to purely aligned can improve electroelastic properties of a printed nanocomposite. Finally, this work provides the first experimental validation of the theoretical and FEM models through measurement of the electroelastic properties of the nanocomposites containing barium titanate nanowires in a polydimethylsiloxane (PDMS) polymer matrix.

# Working towards a Multivalent Battery: Effects of d-electron (de)localization on Ion Transport in Chevrel Phase $Mo_6S_8$ (AGSR_89)


## Everardo Olide[1], Donald Siegel[1,2,3]

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Multivalent ion technologies offer a means to increase theoretical capacity and energy density by merely doubling, evening tripling the number of electrons stored per ion. Mg, Ca, and Al are far more abundant in the earth's crust than Li leading to cheaper, energy dense alternatives for energy storage devices. The current body of knowledge narrows exploration of these technologies which is limited by the materials that can efficiently intercalate the higher valence ions. Chevrel Phase $Mo_6S_8$ has shown to be the only material that can charge and discharge multivalence ions such as $Mg^{2+}$ and $Ca^{2+}$ effectively, giving hope to a viable rechargeable Calcium or Magnesium battery. Despite investigations and construction of a low voltage magnesium battery using the Chevrel Phase material, the intercalation mechanism remains uncertain.

In this study, we investigate how (de)localization of d-electrons affects ion migration in the unique Chevrel Phase material. We perform Density Functional Theory (DFT) calculations with a GGA+U functional which allows the tuning of coulombic repulsion of electrons in specific atomic orbitals dialing electron (de)localization. We anticipate that agile redistribution of delocalized electrons provides ample shielding of the migrating ion, lowering the activation energy barrier, leading to facile transport. This work will contribute to understanding other transport mechanisms in solids that can also be used for Li-ion technologies. Understanding what grants this material efficient shielding of higher valence ions during transport can lead to exploration of a new frontier in multivalent batteries.

# Out-of-Band Acoustic Remote Sensing in Ocean Environments (AGSR_91)

## Alexander Douglass, David Dowling

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Acoustic remote sensing with techniques such as beamforming are well studied and understood. Conventional beamforming methods, as with most signal processing techniques, are limited to processing at the in-band signal frequencies. Lower-than-desired signal frequencies can lead to poor resolution in determining source location or direction-of-arrival (DOA). Higher-than-desired signal frequencies can lead to poor localization due to array sparseness, wavefront mismatch, array geometry uncertainty, or signal scattering from rough boundaries, environmental fluctuations, and physical scatterers.

Out-of-band beamforming methods, specifically frequency-difference and frequency-sum beamforming, aim to reduce the impact of these scenarios by processing signals at a frequency either below or above the signal bandwidth. This is accomplished by generating an out-of-band field, the frequency-difference or frequency-sum autoproduct, which is a quadratic product of complex signal amplitudes at two different frequencies, $AP(\Delta\omega = \omega_2 - \omega_1) = P(\omega_2)P^*(\omega_1)$ or $AP(\Sigma\omega = \omega_2 + \omega_1) = P(\omega_2)P(\omega_1)$. Herein, the performance of out-of-band methods for the purposes of remote sensing in ocean environments is considered. Ocean experiments including imposed uncertainty, sparseness, and complex environmental parameters consider performance in a real ocean environment. Frequency-difference beamforming is shown to be more robust to sparseness and environmental uncertainty, while frequency-sum beamforming is shown to improve image resolution. In addition, out-of-band fields are shown to maintain expected in-band trends in array coherence. The background of these out-of-band methods and experimental results are presented here.

## Cellular Communication Via Force Propagation in Fibrous Microenvironments (AGSR_93)


### Christopher D. Davidson, Brendon M. Baker

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


The ability of cells to communicate with each other to coordinate their activity is crucial to the specification, development, and homeostatic function of all tissues. Intercellular communication via secretion of biochemical signals or through cell-surface receptors has been extensively studied, but a newer method of cell-cell communication has recently been suggested – mechanical communication via propagation of cell-generated forces through the extracellular matrix (ECM). The long-range nature and directionality of mechanical signals make this type of communication unique, and it has been observed in a variety of settings spanning different cell types, distinct ECM settings, and at scales ranging from multicellular clusters to single cells. The generation and transmission of cellular forces largely depends on the mechanical properties of the underlying ECM, and fibrous microenvironments have been theorized to be an optimal structure by which mechanical signals can be propagated. However, commonly used fibrous materials to study cell behavior *in vitro*, such as collagen and fibrin, lack mechanical and architectural tunability for mechanistic studies in order to understand the relationship between ECM physical properties and mechanical communication.

Here, we adopted a previously developed synthetic fibrous ECM mimetic composed of electrospun dextran methacrylate (DexMA) fibers possessing well-defined and tunable mechanical and biochemical properties (Fig. 1a). We first seeded endothelial cells (ECs) at a range of cell densities on compliant matrices (E = 1.5 kPa). At high seeding densities, ECs spread, physically reorganized matrix fibrils, and formed cellular interconnections. Interestingly, at low seeding densities, isolated cells remained unspread, suggesting that a minimum spacing to enable cells to sense traction forces may be required for spreading (Fig. 1b). To more deeply investigate how mechanical signals from individual cells are propagated through these matrices, we

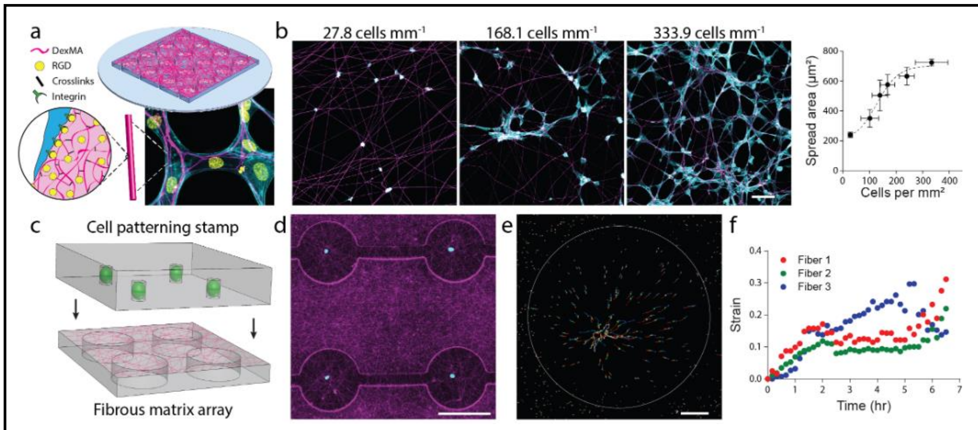


Figure 1. a) Schematic of DexMA fiber matrices. b) Cell spread area as a function of local cell density. c,d) Method for patterning individual ECs. e) Matrix displacements and f) fiber strain over a 7-hour period.

utilized a microfabrication-based method in order to pattern single cells onto suspended matrices (Fig. 1c,d). Through timelapse imaging of ECs and 1 µm fluorescent beads embedded in fibers, we can observe cell force-mediated matrix deformations and quantify fiber strain as the cell spreads on matrices with variable physical properties such as well diameter, fiber stiffness, and fiber density (Fig. 1f). These results will provide us with ECM conditions that maximize the propagation of cell-generated forces in order to intelligently design biomaterials that promote long-range mechanical communication for tissue engineering applications.

## Phenotype Kinetic Metrics to Characterize Heterogeneous Drug Response in Tumor Cells (AGSR_95)


### Natacha Comandante Lou, Divya Venkat, Mohammad Fallahi-Sichani

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The current standard to assess drug response in tumor cell lines relies on population-based measurements of viability or growth rate inhibition at a fixed time-point, typically 72-96 hours, following drug exposure. This approach does not capture the dynamics of response or explicitly separate different drug-induced phenotypic effects. Moreover, heterogeneous drug sensitivities within a cell population would not be distinguished in bulk measurements. We hypothesize that the dynamics of cellular response vary in different cell-drug conditions and that drugs targeting different pathways would contribute at variable degrees to tumor cell killing and proliferative arrest. Here we use kinetic rates of death and division events, measured at a single-cell level, as a function of time using time-lapse live-cell microscopy, as a means to quantify melanoma cell drug responses to various drugs and drug combinations. We show that drug response dynamics vary across different conditions and that some drugs only inhibit cell division whereas others induce cell death and inhibit cell division concomitantly. Furthermore, the kinetic rate measurements enable us to capture low-frequency events, including adaptive changes in drug response that are missed in bulk population measurements. These metrics could be used to improve mechanistic understanding of drug action and adaptation in tumor cells as well as identifying effective combinatorial treatments to minimize drug resistance.

# Experimentally Determining the Magneto-resistance Tensor of Unintentionally Doped (010) β-$Ga_2O_3$ (AGSR_96)


## Zumrad Kabilova, Rebecca L. Peterson

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The beta-phase of gallium oxide (β-$Ga_2O_3$) is a promising material for next generation power electronics due to its ultra-wide bandgap of 4.5 – 4.8 eV and ease of high-quality bulk growth with melt-growth techniques. The crystal structure of β-$Ga_2O_3$ is monoclinic with *C2/m* space group. Due to the low symmetry of the material, possible anisotropy in charge transport can be expected. Therefore, in this work, four-point probe and Hall effect measurements were performed on unintentionally doped (010) β-$Ga_2O_3$ bar-shaped substrates diced along [001], $[100]^*$ and $[001]^*$ directions to determine the elements of material's magneto-resistance tensor. No notable anisotropy has been observed in the electrical conductivity as the difference in the in-plane resistivity was within 3%. The measured Hall voltage was corrected for non-ideal effects such as misalignment, Seebeck, Nernst, and Righi-Leduc effects. Among the four, misalignment of contacts was found to be the dominant non-ideal effect. At room temperature, Hall electron concentration and mobility were ~ 7-8 × $10^{16}$ $cm^{-3}$ and 130 – 140 $cm^2$ $V^{-1}s^{-1}$, respectively. The results of Hall electron mobility among the samples were within 4 – 10 %. The larger difference in mobility could be attributed to the direction-dependent electron-phonon coupling strength in β-$Ga_2O_3$. Due to the monoclinic structure of β-$Ga_2O_3$ and orthogonal coordinate system required for the magneto-resistance tensor calculations, the elements of the tensor denote the values along one crystallographic axis ($\boldsymbol{c}$ or $\boldsymbol{a}$) and a direction orthogonal to it ($\boldsymbol{a}^*$ or $\boldsymbol{c}^*$). Using the experimentally measured values for $\boldsymbol{c}\boldsymbol{a}^*\boldsymbol{b}$ – system, we found the values for $\boldsymbol{c}^*\boldsymbol{a}\boldsymbol{b}$ – system using a matrix transformation. A 3 % difference was observed between the experimentally measured values and the ones obtained through the matrix transformation.

# A Polymeric Nanoparticle Platform for the Prevention of Allogeneic Skin Transplant Rejection (AGSR_98)


**Kevin Hughes[1], Saeed Daneshmandi[3], Sahil Shah[3], Angela Bedoya[1], Liam Casey[2], Lonnie Shea[1,2], Xunrong Luo[3]**

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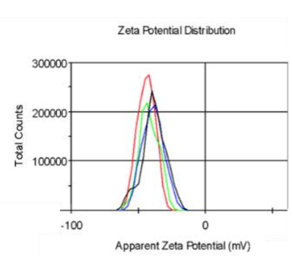
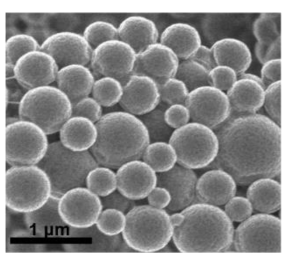
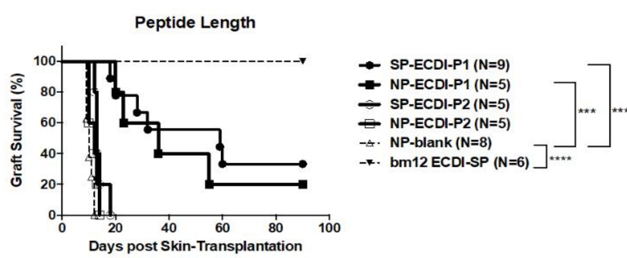
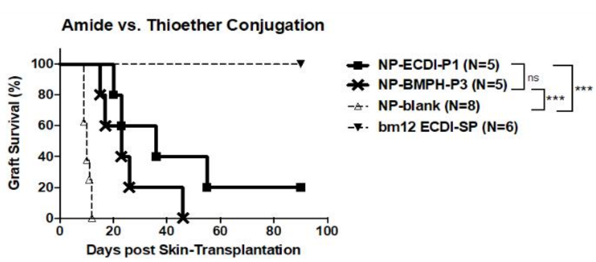
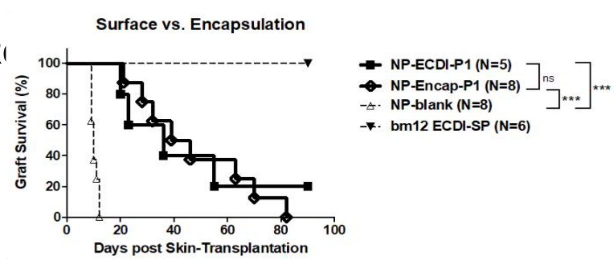
A regimen to promote acceptance of allogeneic grafts involves prophylactic administration of donor splenocytes (SP) treated with 1-ethyl-3-(3′-dimethylaminopropyl)-carbodiimide (ECDI) treatment to induce apoptosis. This and similar cellular platforms are severely limited by the availability of donor cells, cost of *ex vivo* cell manipulation, and the regulatory hurdles associated with cell-based therapies.  Polymeric nanoparticles (NP) have been utilized to induce antigen specific clinical tolerance in multiple immune models and are currently undergoing clinical development. NP-mediated delivery of donor antigens is a promising as an alternative to cell-based therapies for transplant rejection; however, the efficacy donor ECDI-SP have yet to be matched in this context by NP-based technologies. Here, we aim to utilize a skin transplant model of defined major histocompatibility antigen mismatch to optimize the design of poly(lactide-co-glycolide) (PLG) NPs for delivery of synthesized donor peptides. We used the B6.C-H-2$^{bm12}$(bm12) to C57BL/6 (B6) skin transplant model to accomplish several objectives, including understanding the contributions of (1) peptide length; (2) conjugation chemistry; (3) degree of surface expression of protein; and (4) antigenic source to the efficacy of transplantation tolerance. NP were synthesized via oil in water emulsion using the surfactant poly(ethylene-alt-maleic anhydride) prior to intravenous administration in recipient mice. We have demonstrated that, in this model, reducing peptide length increased graft survival and antigen-specific T cells responses. Importantly, the delivery of donor antigen by NP and control *recipient* SP conferred equivalent graft protection, suggesting that the mechanism of tolerance involves features unique to *donor* SP. Interestingly, modification of antigen conjugation (via amide, disulfide, and thioether bonds) did not significantly alter graft survival. Further, comparison of delivery of relevant donor peptide was as effective as delivery of whole cell lysate. These studies support continued development of NP platforms for immunoregulation to achieve a cell-free and biocompatible carrier that is suitable for clinical translation.

# Reconfigurable Light Diffraction Response of Colloidal Ellipsoids by Electric Field Assisted Assembly (AGSR_99)


## Peng-Kai Kao[1], Bryan J. VanSaders[2], Michael D. Durkin[1], Sharon C. Glotzer[1,2], and Michael J. Solomon[1]

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We use alternating current (AC) electric field assisted assembly to produce two-dimensional millimeter-scale arrays of uniaxial ellipsoidal colloids and study the kinetics of their phase reconfiguration by means of light scattering and computer simulation. We find that reconfigurable kinetics of colloidal assembly can be effectively manipulated by tuning the shape of colloids: compared to spheres, ellipsoids with aspect ratio 2.04 disassemble to disordered structures 5.63 times faster and assemble to ordered crystals 1.49 times faster. Small-angle light scattering (SALS) quantifies the light diffraction response, which is sensitive to the kinetics of positional and orientational ordering in the self-assembled anisotropic structures. Confocal microscopy is used to directly visualize local defect structures in the self-assembled structures. This study therefore quantifies the fundamental relationship between the quality of the real space crystal structure (as determined by the microscopic-scale arrangement of defects) and the intensity of the light diffraction response (which integrates over the microscopic defect states to yield a macroscopic characterization). We show three different light diffraction patterns measured from different real space structures: a phase with high orientational order (chain-like structure), a phase with high positional and orientational order (close-packed structure), and a phase with neither positional nor orientational order (glass). Here, the self-assembled structures are created with polystyrene ellipsoids of aspect ratio 2.04 (with major axis 6.54 μm and minor axis 3.2 μm). Compared to spheres, these particles possess an additional rotational degree of freedom for tailoring the optical/structural properties of the assembly. This research contributes to the understanding of reconfigurable kinetics and optical properties of anisotropic colloidal crystals, and is useful for designing the brilliance of structural color as well as kinetics of camouflage at visible and infrared wavelengths.

# Electrical Performance of Annealed Zinc-Tin-Oxide Thin-Film Transistors Deposited by Atomic Layer Deposition (AGSR_100)

**Christopher Allemang[1], Orlando Trejo[2], Carli Huber[2], Neil P. Dasgupta[2], Rebecca L. Peterson[1]**

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Fabrication of devices on top of existing complimentary metal-oxide-semiconductor (CMOS) substrates is being studied as a way to increase device density and continue Moore's law. Zinc tin oxide (ZTO), an amorphous oxide semiconductor, is a strong candidate for heterointegration of thin film devices on CMOS owing to its wide bandgap (~3 eV), high electron mobility, and large area uniformity. Heterointegration of AOS on CMOS requires fabrication of high-performance devices using low temperature deposition techniques to preserve the underlying CMOS device performance. Among the potential candidate techniques, atomic layer deposition (ALD) is a promising low temperature thin film deposition process allowing precise control of film interface, stoichiometry, and thickness.

In this project, bottom-gate top contact thin film transistors (TFTs), as illustrated by the cross section in Figure 1, were fabricated with ALD ZTO thin films. The electrical properties of ZTO TFTs were studied as a function of annealing temperature and Zn:Sn ratio. The Zn:Sn ratio of the films was varied by changing the Zn:Sn ALD cycle ratio. X-ray photoelectron spectroscopy was used to study the Zn:Sn ratio and capture chemical composition changes with annealing. As an alternative to traditional patterning performed for device isolation via photolithography and etching, polymethyl methacrylate (PMMA) was studied as an ALD ZTO inhibition layer to enable additive manufacturing via area-selective ALD. In this way, a patterned layer of PMMA inhibits the growth of ZTO where present, depositing ZTO only in specified un-coated areas. This work presents a pathway towards scalable nanomanufacturing of electronics on a range of temperature-sensitive substrates.

This work was supported by a National Science Foundation Scalable Nanomanufacturing award #1727918.

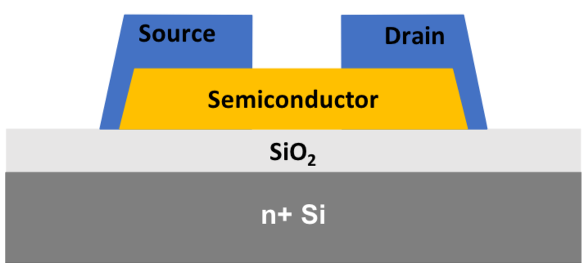


Figure 3: Cross section of bottom gate top contact TFT.

# Effect of Crystal Quality on the Brilliance of Structural Color from Self-Assembled Colloidal Crystals (AGSR_101)

**Tianyu Liu[1], Bryan Vansaders[2], Sharon C. Glotzer[1,2,3], Michael J. Solomon[1,3]**

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Here we report a fundamental understanding of the relationship between self-assembled colloidal crystal quality and the brilliance of structural color from crystals. Structural color has potential applications in optical materials because this color arises due to light diffraction from periodical arrays and is not prone to chemical degradation. To establish the relationship between colloidal crystal quality and the brilliance of structural color, we studied two variables: First, we quantified the thickness of self-assembled colloidal crystals, so as to understand how this parameter of crystal quality determined the brilliance of structural color. Second, we incorporated dopants into the self-assembly process to probe how impurities affected crystal quality and structural color brilliance. We have integrated experiment and simulation studies to yield an understanding of how crystal thickness and impurities concentration mediate structural color brilliance. In the experiments, we assembled polystyrene microspheres into colloidal crystals with different thickness by using the solvent evaporation method. The thickness profiles were characterized by cross-sectional scanning electron microscopy and profilometer. Spectral response of colloidal crystals measured with a white light spectrophotometer showed that the brilliance of structural color increased as the crystal thickness increased. Additionally, we manipulated the defect structures of colloidal crystals by introducing differently sized particles as impurities. As the concentration of the impurity spheres increased, the brilliance of structural color reflection decreased. In the simulation, we generated simulated crystal structures with defects using HOOMD-Blue. A defect-free crystal was prepared with crystal planes [111] parallel to a repulsive wall in the XY plane of the simulation. For defective crystals with impurity particles, a fraction of particles was randomly chosen and their radii gradually changed to match the desired impurity particle radius. We simulated the reflection spectrum of defect structures with Finite Difference Time Domain (FDTD) algorithm. The simulation results were used to validate the experimental results that crystal thickness and impurities concentration quantitatively affected structural color intensity. Those findings guide the design of optical materials to tune structural color intensity.

## Self-Healing Composites Materials (AGSR_104)


### Lisha Zhang

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Carbon fiber reinforced polymer (CFRP) composites were fabricated using a novel intrinsically healable isocyanurate-oxazolidone (ISOX) thermosetting matrix. After multiple delamination events, repeatable strength recovery of the composites has been demonstrated with a first healing efficiency up to 85% after thermal treatment. The healing mechanism results from transformation of the isocyanurate with epoxide groups to yield new oxazolidone rings at the fracture surface. This novel ISOX polymer utilizes commercial diglycidyl ether of bisphenol F (DGEBF) and toluene diisocyanate to produce a high cross-link density thermoset with a glass transition temperature ($T_g$) up to 285 °C, and 99.5% of the composite weight remains at 300 °C. The strength and stiffness of the composites are comparable with an engineering grade polymer matrix composite typically used in aerospace applications and the thermal stability places the materials in the polybismaleimide performance region although with greater toughness. This polymer exhibits the highest $T_g$ of any self-healing material reported and is composed of low cost reactants, which gives the polymer great potential to function as a major component of an advanced structural composite for extreme environments.

# Dynamics of Cavitation Bubble Near an Interface During the Inertial Collapse (AGSR_105)

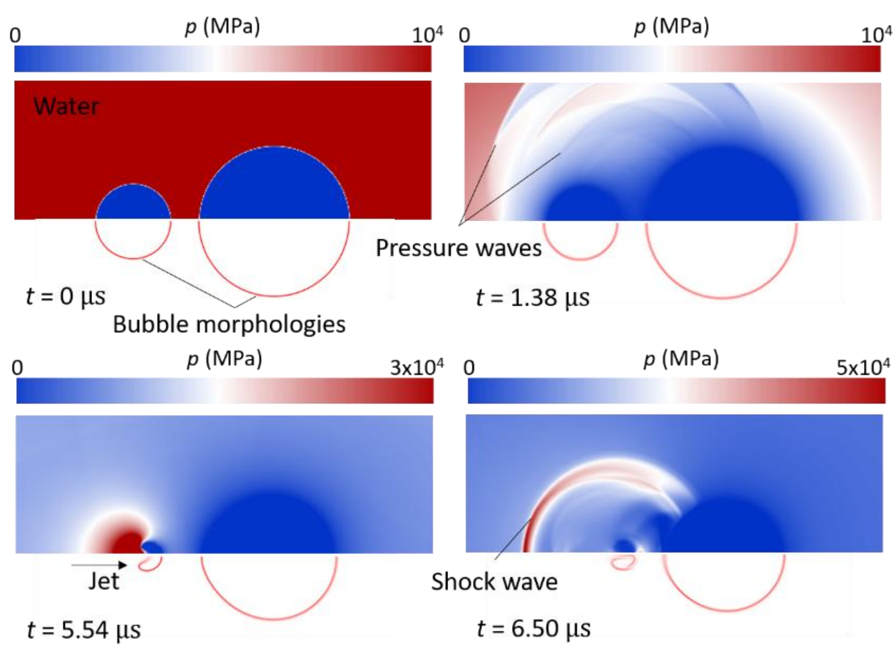

## Minki Kim, Shahaboddin Alahyari Beig, Mauro Rodriguez, Eric Johnsen

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


Cavitation is observed in various hydraulic systems due to the pressure drop in the flow, such as in nozzle contractions, downstream of a hydrofoil and a pump in internal combustion engines. In these systems, the liquid undergoes vaporization and the subsequent rupture in the liquid nucleates cavitation bubbles forming a bubble cloud. Bubbles respond to the pressure gradient in the flow by oscillating in volume. In extreme conditions, a bubble collapses and emits a shock wave with pressure up to two or three orders of magnitude larger than the ambient pressure. The impact load from this shock wave can damage neighboring surfaces. In naval hydraulic applications, the repeated impact loads to the surface lead to undesired equipment failure. In medical applications, the damage is desired in non-invasive ultrasound therapy tools used for cancer tissue ablation.

Understanding cavitation-induced damage is necessary to develop mitigation/enhancement strategies in naval hydraulic systems and medical therapy tools. However, the nonlinear interactions between the bubbles and the wide range of spatial and temporal scales pose a significant challenge in experimentally and computationally studying bubble clouds. To gain fundamental understanding of bubble-bubble interactions, the 3D compressible Navier-Stokes equations for gas-liquid flows are solved numerically using a solution-adaptive high-order accurate method. We consider the simplified configuration involving a single bubble inertially collapsing near a larger secondary bubble. The initial secondary bubble radius ranges from finite to infinite (e.g., flat free surface) size.

As bubble collapses, pressure waves produced during the collapse interacts affecting bubble collapse morphology and resulting emitted shock waves. Thus, we vary driving pressure, initial distance between the primary bubble and secondary interface and initial bubble size ratio to determine the effect on the bubble-bubble interactions (i.e., bubble deformation, jet velocity and strength, and minimum bubble volume), and resulting shock waves and maximum pressures. Three different regimes classifying the different bubble morphologies and jet types are also presented.



# Flexibility Polytopes for Aggregated Energy Resources: Computation and Applications (AGSR_106)


## Md Salman Nazir[1], Ian Hiskens[1], Andrey Bernstein[2], Emiliano Dall'Anese[3]

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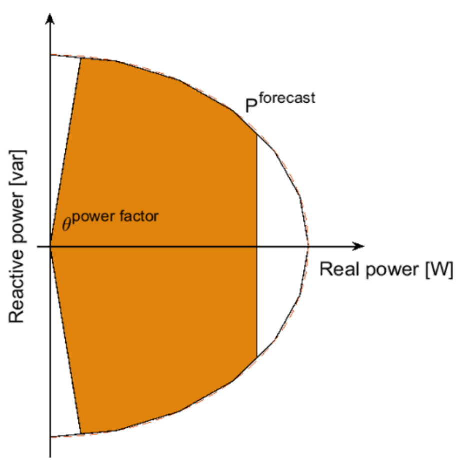
Power systems have been accommodating a significant amount of distributed energy resources (DERs), such as solar photo-voltaic (PV) systems, batteries, electric vehicles and controllable loads. The flexibility from DERs can be used to address many problems in the power grid. For example, PV inverter set-points can be optimized to provide reactive power support and efficiently deal with voltage issues. Controllable loads, such as air-conditioners and refrigerators, can balance fluctuations from renewables and reduce peak network demand by essentially acting as virtual batteries. Due to these, there has been increasing effort on characterizing the flexibility available from DERs and on the aggregation of such flexibility.

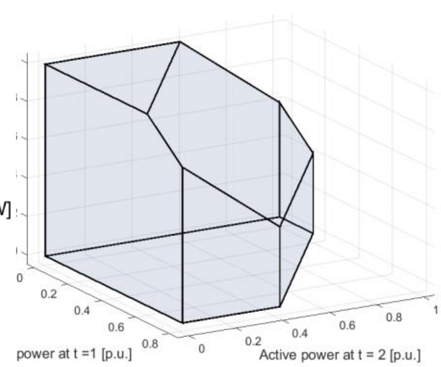
The flexibility polytope of a single PV inverter, as shown in the figure below, captures all feasible active and reactive power operating points. The flexibility polytope of a battery or a storage-like load extends to higher dimensions to capture the internal state of charge dynamics over several time-periods. The aggregate flexibility from a population of DERs can be obtained by computing the Minkowksi sum (M-sum) of the individual feasible sets. However, since M-sum represents the element-wise summation, the exact computation of M-sum is computationally very challenging, especially in higher dimensions (4-D and above) and for a large population.

In this work, we develop and compare algorithms to compute M-sum approximations of flexibility polytopes. Using a novel polytope decomposition and an interval summation technique, we show how the aggregate polytopes can be rapidly computed. Unlike many existing algorithms that work only in low dimensions, our algorithm extends efficiently to higher dimensions. Using our method, the approximation accuracy reached 95% in a 2-D case, within 20 seconds, and 70% in an 8-D case, in less than a minute. These aggregate flexibility polytopes are finally used in an optimal power flow problem to provide voltage support in a power distribution grid and to attain optimal charging schedules for a population of air-conditioners and electric vehicles.

**Flexibility Polytopes for (a) a PV Inverter and (b) an Air-conditioner**




(a)




(b)

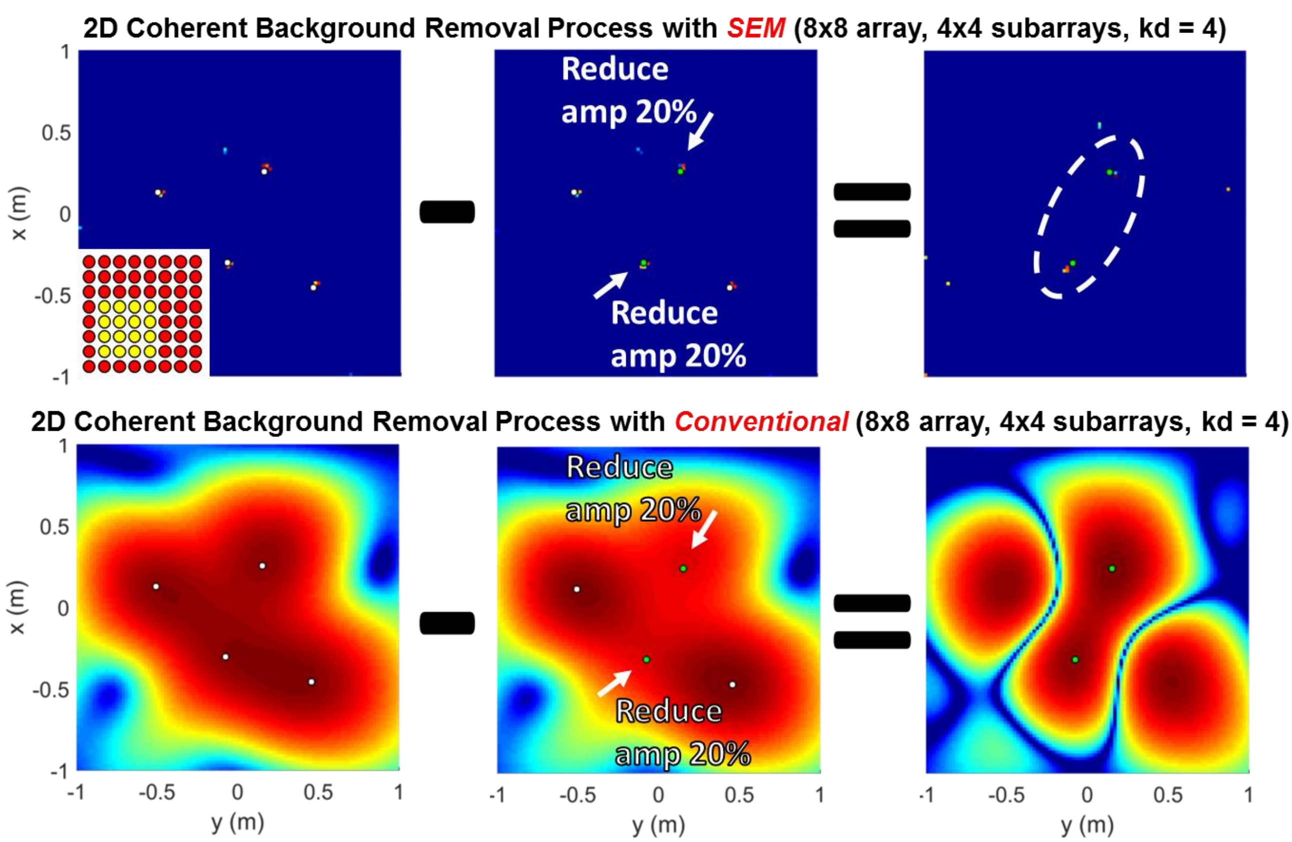
# 2D High-Resolution Acoustic Localization for Structural Health Monitoring (AGSR_107)


## Tyler Flynn, David Dowling

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



Many high-resolution techniques exist for localizing acoustic sources; however, many of these methods suffer when applied to data containing spatially separated coherent signals. The Spectral Estimation Method with Additive Noise (SEMWAN) is an existing beamforming technique that allows for high-resolution localization of monopole sources in addition to good performance in low SNR environments via the subtraction of a reference measurement of background noise. Though SEMWAN suffers for cases involving mutually-coherent signals – such as distributed radiating sources – it has previously been extended to 1-D coherent source problems by implementing the additional step of subarray averaging. Furthermore, this enables the subtraction of *coherent* background signatures thereby permitting localization of small changes (e.g. localized damage) provided a known baseline array recording is available. This presentation discusses the extension this approach to two-dimensional problems using cartesian planar arrays. Experimental results using multiple coherent sources and a remote receiver array (with varying numbers of elements and subarray geometry) are analyzed and compared against simulation. Application toward the localization of mechanical changes in a 12” square aluminum plate is also addressed. [Sponsored by NAVSEA through the NEEC and by the US DoD through an NDSEG Fellowship]

# Optimal Capacity Design for Distributed Energy Resources in Islanded Microgrid Using a Stochastic Approach (AGSR_110)

## Sijia Geng, Ian A. Hiskens

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

Islanded microgrid is a standalone small scale power system that groups a variety of distributed energy resources (DERs), especially renewables, together with energy storages and loads to provide better control and operation. It is a viable solution for power supply to rural area. Microgrid also provides a new perspective to deal with the intermittency and uncertainty of renewables such as wind and solar hence increases the penetration of renewables in modern power system.

The challenge in islanded microgrid is that it's not connected to the main power grid, which mandates sufficient energy production to safely supply demand at all time. On the other hand, excessive capacity design should be avoided to keep the microgrid cost-effective. Hence, our objective is to optimally design the capacities for a variety of DERs in an islanded microgrid to guarantee energy sufficiency as well as minimize the cost.

In this work, mathematic models are formulated for various DERs, including wind turbine generators, solar photovoltaics (PV), batteries, fuel cell systems, and plug-in electric vehicles. Economic factors such as initial investment, replacement cost, and maintenance cost are also considered. To capture the intrinsic uncertainty within wind turbine, solar PV and loads, stochastic models are built for each of them. A stochastic chance-constrained optimization problem is formulated to handle the random variables, which is solved through scenario-based approach. The optimal solution describes the capacities of each type of DERs that give the minimum overall cost during the microgrid lifetime, while sufficiently supplying the loads.

The results indicate that certain types of DER such as fuel cell is too expensive to be employed in current situation, considering other cheaper resources such as wind turbine and solar PV. Battery storage system is an integral component due to the intermittency of renewables, while electric vehicle is also a viable storage resource to be utilized.

# A Multidisciplinary Framework to Assess Seismic Resilience of Communities (AGSR_111)


## Omar A. Sediek, S. El-Tawil, J. McCormick

*Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, Michigan.*



Over the past decade, the concept of community resilience has gained much attention in science and policy circles in response to the increase in frequency and severity of disaster events. Assessment of seismic resilience of communities requires modeling the interactions that take place between the multiple systems of society, including engineering, economic, social, financial, environmental, political, and others. The complex interdependencies that arise between these systems is challenging to model because of the multi-disciplinary nature of the problem and range of temporal and spatial scales involved. With this motivation, a fully scalable and adaptable multidisciplinary framework is developed for modeling the seismic resilience of communities. The framework includes different simulators, each of which represents various aspects of the problem, such city layout, regional seismic ground motions, structural response, structural and non-structural damage and loss assessment. Each simulator is considered as a black box that takes inputs from other simulators and provide outputs in a specific format to be used by other simulators. The developed framework adopts FEMA P-58 as a loss estimation method providing rigorous probabilistic seismic performance assessment of each building in the community. Real time simulation is used by stepping through time during the earthquake (time step in terms of milliseconds) and recovery stage (time step in terms of days) providing high flexibility in including any interdependencies that could arise during the disaster itself or the recovery stage. The proposed framework is demonstrated through an introductory case study that is focused on modeling the resilience of an archetype community facing a seismic hazard.

# $MoS_2$ Memristors Exhibiting Variable Switching Characteristics towards Bio-Realistic Synaptic Emulation (AGSR_112)

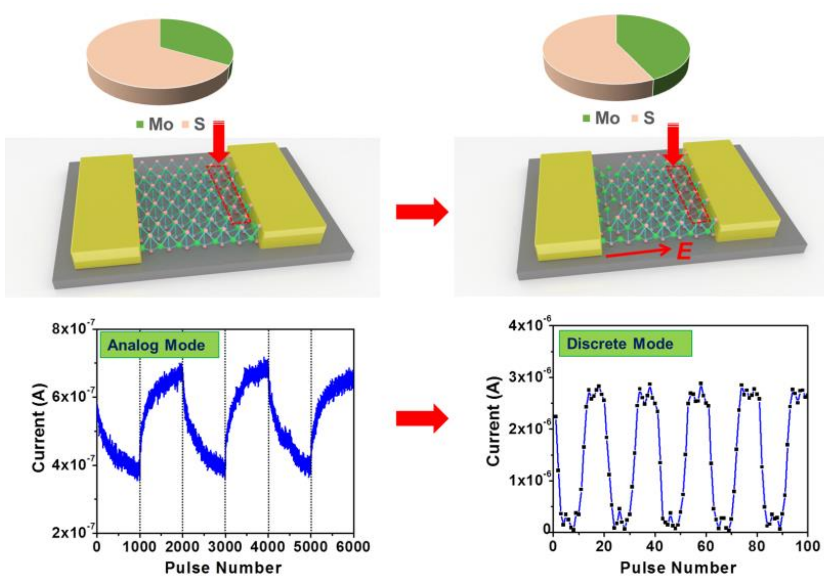

## Da Li[1], Bin Wu[1], Xiaojian Zhu[2], Juntong Wang[1], Byunghoon Ryu[1], Wei D. Lu[2], Wei Lu[1], Xiaogan Liang[1]

*[1]Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI*

*[2]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*



Memristors based on 2D layered materials could provide bio-realistic ionic interactions and potentially enable construction of energy-efficient artificial neural networks capable of faithfully emulating neuronal interconnections in human brains. To build reliable 2D-material-based memristors suitable for constructing working neural networks, the memristive switching mechanisms in such memristors need to be systematically analyzed. Here, we present a study on the switching characteristics of the few-layer $MoS_2$ memristors made by mechanical printing. We found that an as-fabricated $MoS_2$ memristor initially exhibits an analogue pulse-programmed switching behavior, but it can be converted to a quasi-binary memristor with an abrupt switching behavior through an electrical stress process. Such a transition of switching characteristics is attributed to field-induced agglomeration of vacancies at $MoS_2$/metal interfaces. The additional Kelvin probe force microscopy, Auger electron spectroscopy analysis, and electronic characterization results support this hypothesis. Finally, we fabricated a testing device consisting of two adjacent $MoS_2$ memristors and demonstrated that these two memristors can be ionically coupled to each other. This device interconnection scheme could be exploited to build neural networks for emulating ionic interactions among neurons. This work advances the device physics for understanding the memristive properties of 2D-material-based memristors and serves as a critical foundation for building bio-realistic neuromorphic computing systems based on such memristors.

# Emerging Graduate Student Research (EGSR) Poster Session

## 1:00 pm – 2:30 pm

Pierpont Commons Atrium and Hallway

# Ultrathin, Lightweight and Flexible Organic Light-Emitting Devices with a High Light Outcoupling Efficiency (EGSR_2)

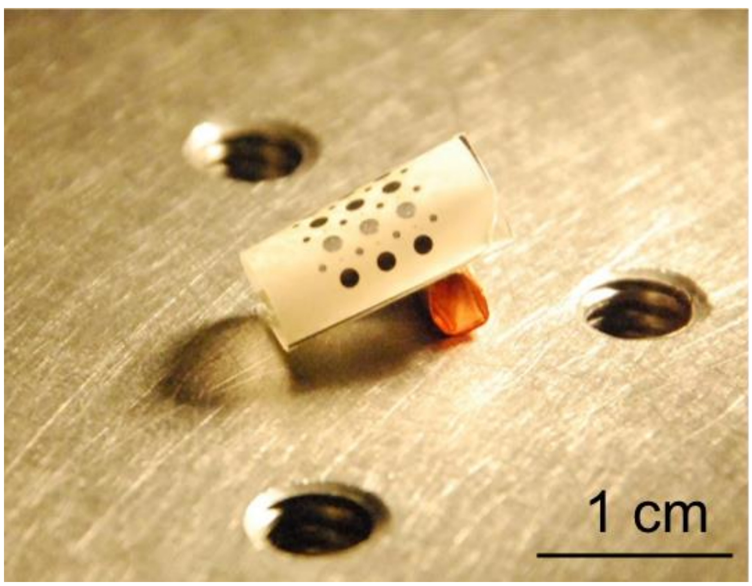
**Xiaheng Huang[1], Yue Qu[1], Dejiu Fan[1], Jongchan Kim[1], Stephen R. Forrest[1,2,3]**

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

[2] *Department of Physics, University of Michigan, Ann Arbor, MI*

[3] *Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI*

High-efficiency, flexible organic light-emitting diodes (OLEDs) are of interest for display and lighting applications. However, they often suffer from inefficient light extraction, and many outcoupling schemes are incompatible with flexible OLEDs. Here, we demonstrate a corrugated, ultrathin (10 μm), light-weight (20 g/m$^2$), and flexible OLED on a polychloro-p-xylylene (parylene) substrate. A visible-wavelength-scale random corrugation pattern is imprinted on both surfaces of the parylene substrate. The pattern efficiently outcouples the trapped susbstrate substrate, waveguide and surface plasmon modes. The corrugated parylene OLED (CP-OLED) has an external quantum efficiency, 27.8 ± 1.7% compared with 20.5 ± 1.3 for devices on conventional flat glass substrates. The CP-OLED shows a Lambertian emission profile with identical spectra at viewing angles from 0 to 90 degrees from normal.



## Increasing GPS Localization Accuracy Using Reinforcement Learning (EGSR_3)


### Ethan Zhang, Neda Masoud

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



We propose a reinforcement learning framework to increase GPS localization accuracy. The framework does not make any assumptions on the GPS device hardware parameters or motion models, nor does it require infrastructure-based reference locations. The proposed reinforcement learning model learns an optimal strategy to make ``corrections'' on raw GPS observations. The model uses an efficient confidence-based reward mechanism, which is independent of geolocation, thereby enabling it to be implemented anywhere. We use a map matching-based regularization term to reduce the variance of the reward return. We implement the asynchronous advantage actor-critic (A3C) algorithm, a parallel training protocol, for training our model. A3C facilitates short training sessions and provides more robust performance. Our real-world experiments demonstrate that using A3C we can obtain an optimal policy in about 800 steps in a training session with 4 threads. We visualize the corrected GPS locations next to the raw GPS observations to demonstrate the performance of the proposed framework.

# Investigating the Role Assignment Stability in Large-scale Peer-to-Peer Ridesharing Markets (EGSR_4)


## Amirmahdi Tafreshian, Neda Masoud

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



Peer-to-peer (P2P) ridesharing is a form of shared-use mobility, and has emerged in recent decades as a result of enabling of the sharing economy, and the advancement of new technologies that allows easy and fast communication between individuals. A P2P ridesharing system provides a platform to match a group of drivers, who use their personal vehicles, to travel with their peer riders who are in need of transportation.

P2P ridesharing systems are traditionally categorized as two-sided markets, with two mutually exclusive sets of agents, i.e., riders and drivers. Fixing the roles of participants a priori, however, could come at an opportunity cost of missed social welfare/revenue for the system. Consequently, this research proposes a new market game and its corresponding mathematical formulation that outputs matching, role assignment, and pricing. We investigate the stability properties of this market game, and demonstrate its relationship with one-sided markets.

# Excellence in Higher Education Liberian Development (EHELD) Through the Eyes of Female Liberian Engineering Students (EGSR_6)

**Edith Tarplah[1], A. Sillah[1], C. Greenhill[2], A. Murphy[2], A. Cotel[3]**

[1] *Department of Civil Engineering, University of Liberia, Monrovia, Liberia*

[2] *Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI*

[3] *Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI*

In 2011, a grant from the United States Agency for International Development (USAID) was awarded to RTI Inc, the University of Michigan (UM), Rutgers University and North Carolina University. The 5-year project, *Excellence in Higher Education for Liberian Development* (EHELD) focused on transforming the educational system at both the collegiate (University of Liberia (UL) and Cuttington University) and high school level, and aimed to advance both engineering and agriculture programs through targeted programming. The primary goal was to make the learning process in these subjects more interactive, dynamic, and modern in order to provide students the theoretical and practical knowledge needed to enter the workforce upon graduation. The second goal of the initiative was to increase the number of women pursuing STEM degrees. Fifty college students (25 men and 25 women) completed a one-month training program led by both male and female instructors. The training consisted of hands-on, team projects that focused on developing skills in both math and science while teaching the importance of gender, diversity, and identity in team projects. In addition, EHELD provided resources to colleges through building interactive computer and analytical laboratories, and also provided the means for curriculum development. However, despite provided opportunities, unfavorable retention of female students remained, and more than half of the female students left engineering programs each year in Liberia. Top reasons were poor GPA of the students and the long time-commitment for completion of the undergraduate degree (often more than 6 years).

In order to increase retention for females who participated in the EHELD project, the first student chapter of the Society of Women Engineers (SWE) on the African continent was created in 2013. For the last 4 years, a professional development and leadership camp runs each summer, with the collaboration of UM and UL students. These combined activities have created a professional network for female engineering students and professionals in Liberia. The goal of this poster is to report and discuss results of the recent initiatives and impacts on the female engineering student population at both the University of Liberia and the University of Michigan.

# Design and Electrohydrodynamic Jet Printing of Layered Periodic Photopolymers (EGSR_7)

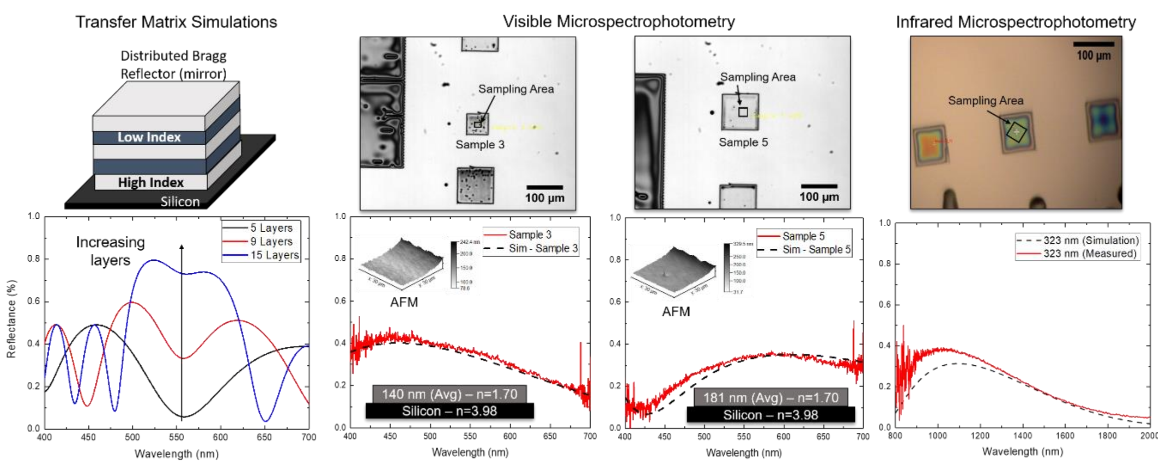
**Brian Iezzi[1], Zahra Afkhami[2], David Hoelzle[3], Kira Barton[2], Max Shtein[1]**

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

*[2]Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI*

*[3]Department of Mechanical and Aerospace Engineering, The Ohio State University, Columbus, OH*

Periodic layered mirrors and optical filters are used for wavelength selection in spectroscopy and imaging. These mirrors have long relied on inorganic materials that have the refractive index contrast necessary to obtain desired electromagnetic wave interference patterns but require cumbersome and expensive manufacturing processes. Photopolymers have been formulated with refractive indices ranging from 1.3 to 1.7, and are, in principle, compatible with versatile, low-cost additive manufacturing processes. We use commercially available high ($n_H$=1.70) and low ($n_L$=1.38) refractive index photopolymers to create periodic layered mirrors and filters. We utilize transfer matrix simulations to design distributed Bragg mirrors having fewer than 15 alternating index layers with reflectance exceeding 60% in the visible range and complementary Fabry-Perot filters using a polymer resonant cavity with narrow transmission peaks of 15 nm FWHM with fewer than 30 layers. Experimental validation of these constructs is done using electrohydrodynamic jet (e-jet) printing; achieving individual layer thicknesses between 100-350 nm and well-defined filter “pixels” below 100 square micrometers. The reflectance/transmission characteristics of the printed mirror/filter “pixels” are measured using spatially selective microspectrophotometry; an in-house system for the visible spectrum (400-750 nm) and a commercial micro-FTIR system for the near infrared (800-2000 nm). Single layers of the high refractive index photopolymer printed on silicon have shown close matching to the transfer matrix simulations across the visible to near infrared (see figure). Various printing parameters, such as utilizing continuous versus pulse printing and their effect on layer interfaces are discussed, along with how this information is used in the multi-physics design of monolithically-integrated organic imaging devices with predictable external quantum efficiency characteristics. These polymer-based optical filters could enable a curved focal plane hyperspectral imager with potential applications in healthcare diagnostics, agriculture, and autonomous vehicle sensing.



## Stochastic Water Distribution Network Operation Considering Power Distribution Network Constraints (EGSR_8)

### Anna K. Stuhlmacher, Johanna L. Mathieu

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

The electric power grid faces resiliency challenges due to increasing levels of intermittent and distributed renewable energy sources. The water distribution network (WDN) and power distribution network (PDN) are spatially and temporally coupled through the power consumption of water pumps and storage capabilities of water tanks. By jointly optimizing operation of the water and power distribution networks, we can ensure that WDN power usage does not exacerbate the violation of constraints in PDNs with high penetrations of distributed energy resources. We formulate a chance-constrained optimization problem to schedule water pumping subject to PDN constraints while managing water demand uncertainty. In addition to an optimal pumping schedule, we also determine optimal parameters of a control policy that can be used to compute real-time control actions to compensate for water demand forecast error. The resulting problem is nonlinear and nonconvex, and so conventional solution approaches for chance-constrained problems do not work. We heuristically apply a scenario-based method and investigate the performance of the control policy in ensuring water demands are met and both WDN and PDN constraints are satisfied despite uncertainty. Through case studies with a detailed model of a coupled WDN/PDN, we find that the scenario-based method provides feasible real-time control actions for most realistic scenarios; however, there is no guarantee that the full range of realistic scenarios can be satisfied at the desired confidence level. Future work will explore alternative solution approaches including convex relaxations and approximations of the formulation.

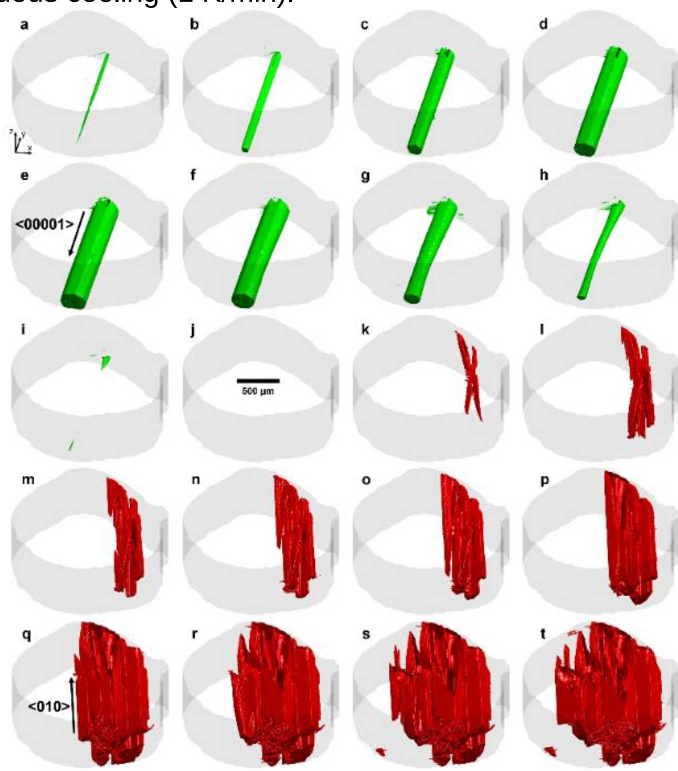
# A Side-By-Side Comparison of the Solidification Dynamics of Quasicrystalline and Approximant Phases in the Al-Co-Ni System (EGSR_9)

**Insung Han[1], Xianghui Xiao[2], Ashwin J. Shahani[1]**

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

[2]*X-ray Science Division, Advanced Photon Source, Argonne National Laboratory, Lemont, IL*

Quasicrystals and their approximants have triggered widespread interest due to the challenge of solving their complex crystal structures as well as their possibly exceptional properties. The structural motifs of approximants are similar to those of the corresponding quasicrystals, but to what extent are their crystallization pathways the same? Unfortunately, there have been very few real-time experimental investigations to answer this question. Here, by leveraging the high penetrating power of hard X-rays, synchrotron-based X-ray tomography was conducted in order to capture the nucleation and growth of a decagonal quasicrystal and its related approximant. The combination of data-driven computational analysis with new thermodynamic databases allowed us to characterize with high precision the constitutional and kinetic driving forces for crystallization. Our experimental results prove that the growth of both crystals from a liquid is dominated by first-order kinetics. Nevertheless, and somewhat surprisingly, significant differences were observed in their rates of nucleation and growth. The reasons for such divergent behaviours are discussed in light of contemporary theories of intermetallic crystallization. The attached figures demonstrate the three-dimensional reconstructions of a decagonal quasicrystal (coloured in green) and X phase crystals (coloured in red). The morphological evolution was captured at the temperature between 1259.8 K and 1215.5 K during continuous cooling (1 K/min).



# Improving Modeling of the Thermospheric Density Using CubeSat Ephemeris Data (EGSR_10)


## D. A. Brandt, A. J. Ridley, C. D. Bussy-Virat

*Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI*



An accurate mathematical description of Earth's thermospheric density is vital to the tracking and orbit maintenance of numerous space assets in Low Earth Orbit (altitude below ~1,000 km). The United States Air Force has chiefly relied on the High-Accuracy Satellite Drag Model (HASDM) for this purpose, which predicts an predicts out to three days, a dynamically varying global density field. HASDM is calibrated using the Dynamic Calibration Atmosphere (DCA), which uses the Jacchia 1970 thermosphere as its base model, employing a least squares differential correction across 75 spherical calibration satellites (Jacchia, 1970). The DCA uses Space Surveillance Network observations directly to perform calibrations every 3 hours, by updating the inflection point temperature at 125 km altitude and the exospheric temperature above 600 km altitude (Storz et al. 2005). The details of the DCA and its calibration results are not available to the public. We thus propose a method to develop an analogue to the DCA for public use, by creation of a calibration method to correct estimates of the thermospheric density. This shall be done through usage of CubeSat ephemeris data, chiefly from QB50 and Planet Labs satellites, to derive the thermospheric density for comparison to predictions by those of the internationally-used empirical global atmospheric density model, NLRMSISE-00. The method will adjust NRLMSISE-00's usage of the parameters Ap and F10.7 in order to reproduce CubeSat ephemeris data by supplying NRLMSISE-00 densities to our in-house orbital propagator, the Spacecraft Orbital Characterization Kit, allowing for calibration of the model to be automated for convenient and accurate application.

# An Augmented Reality Environment for Enhancing Clinical Training Experience: Stroke Assessment Simulation (EGSR_11)


## Ci-Jyun Polar Liang[1], Charles Start[2], Hanna Boley[3], Vineet R. Kamat[1], Carol C. Menassa[1], Michelle Aebersold[3]

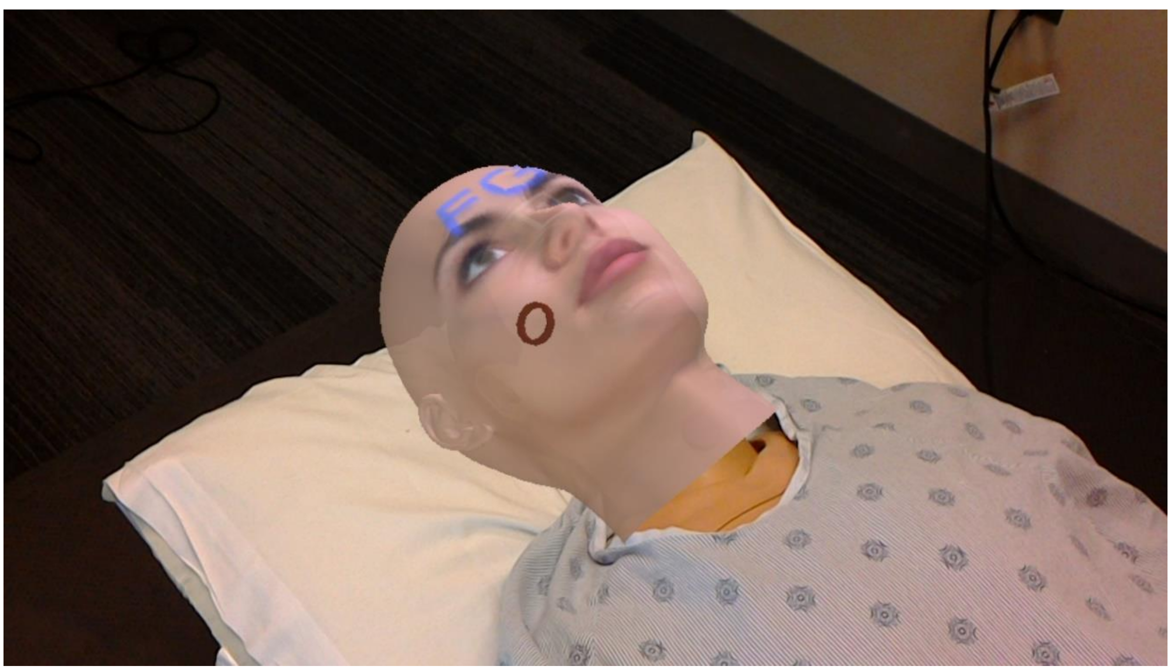
[1]*Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI*

[2]*School of Kinesiology, University of Michigan, Ann Arbor, MI*

[3]*School of Nursing, University of Michigan, Ann Arbor, MI*



The development of virtual, augmented, and mixed reality in recent years is opening doors for using VR, AR and MR devices in education. The purpose of this study was to test the use of augmented reality in teaching healthcare practitioners. To conduct our research, a AR simulation application and an AR refining algorithm were developed for the Microsoft HoloLens that projects a face displaying facial drooping (a symptom of stroke) onto a training mannequin. Students at the nursing school were then placed in a clinical simulation wherein they wore the Microsoft HoloLens and performed a stroke assessment (FAST) of their mannequin patient. The students participated in a survey following their simulations and provided feedback on the devices and the quality of their experience. The results of the study show that most students identified the stroke symptoms without helps from instructor during the simulation and felt that VR, AR and MR will be a very useful educational tool in the near future. Further development of the program and device is underway, and future tests will be conducted. The results from this study will be helpful in further progressing the development of mixed reality, and the use of these devices in healthcare training.

## Classification of Huntington Disease using Acoustic and Lexical Features (EGSR_12)


### Matthew Perez[1], Wenyu Jin[1], Duc Le[1], Noelle Carlozzi[2], Praveen Dayalu[3], Angela Roberts[4], Emily Mower Provost[1]

*[1]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*
*[2]Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor, MI*
*[3]University of Michigan Medical School, University of Michigan, Ann Arbor, MI*
*[4]Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL*


Huntington disease (HD) is a fatal neurodegenerative disease that typically affects 12 per 100,000 people in the Western World. HD is insidious and progressive, affecting motor skills, speech, cognition, and behavior. HD diagnosis is currently done through a one-time genetic test, however, current methods for tracking disease progression involve frequent in-clinic assessment, which is both expensive and relatively inaccessible. The development of an objective, non-invasive acoustic biomarker, sensitive enough to detect disease progression in people with premanifest and manifest HD, will provide new avenues for clinical research and treatments.

Language and speech symptoms are common in HD, occurring in approximately 90% of cases. HD speech is typically characterized by decreases in the number of words pronounced, syntactic complexity, and speech rate, in addition to increases in paraphasic errors, filler usage, and sentence duration. Preliminary research has shown that HD-related speech deficits can be objectively characterized and increase with disease progression, providing an opportunity to leverage changes in speech as a sensitive biomarker for symptom severity tracking. This paper builds towards this goal by investigating how the speech signal can be used to automatically detect the presence of HD.

We present an initial step towards detecting changes in HD severity by first demonstrating the efficacy of using the speech signal for detecting the presence of HD. The system includes transcription, feature extraction, and classification. The transcripts are generated either by humans or by training in-domain automatic speech recognition (ASR) systems. The features are clinically-inspired and include filler usage, pauses in speech, speech rate, and pronunciation errors. We investigate the static and dynamic feature properties. The static feature sets describe speech behavior using summary statistics; the dynamic feature sets provide an opportunity to directly model the feature variation between utterances. We model the static feature sets using k-Nearest Neighbors (k-NN) with Euclidean distance and Deep Neural Networks (DNN). We model the dynamic feature sets using k-NN with Dynamic Time Warping (DTW) Distance and Long-Short-Term Memory Networks (LSTM). We investigate the impact of transcription error, moving from manual transcriptions, to transcripts generated using forced alignment to known prompts, and finally to automatic speech recognition (ASR).

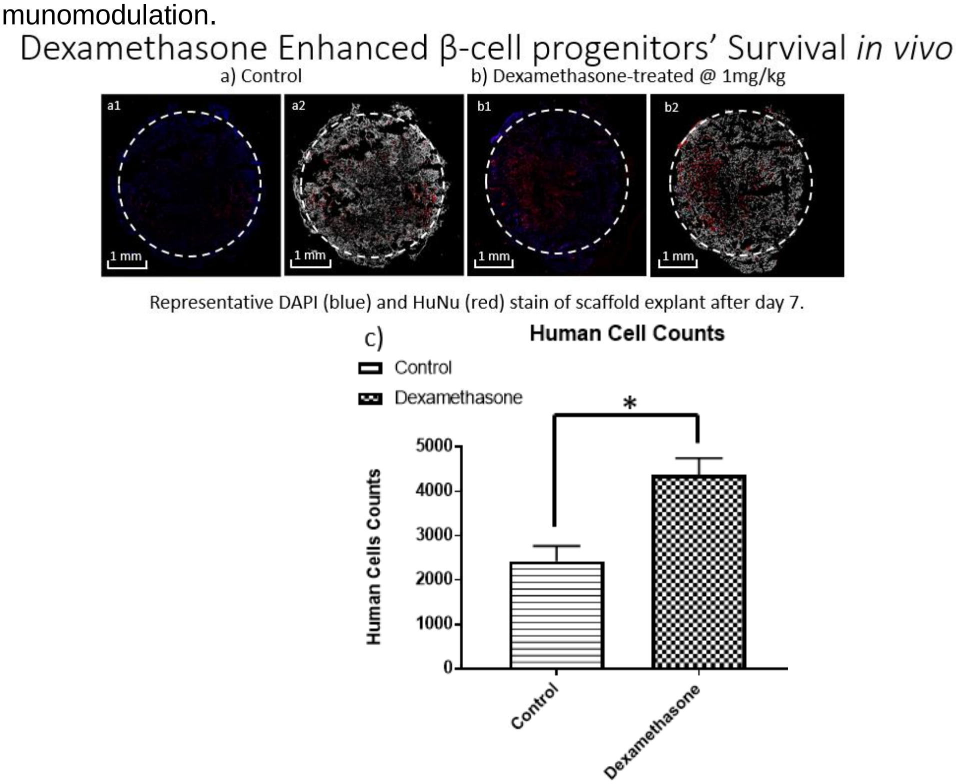
Our results demonstrate the efficacy of speech-centered approaches for detecting HD. We show that we can accurately detect HD using a simple static (k-NN) approach, resulting in an accuracy of 0.81 (chance performance is 0.5). We then show that these results can be improved using dynamic feature sets (DTW) or deep methods, which can capture the non-linear relationships in our feature sets (DNN/LSTM). Finally, we demonstrate that in domains with limited lexical variability, manual transcripts can be replaced with ASR transcripts without suffering from a degradation in performance, even given a word error rate of 9.4%. This indicates the robustness of the identified speech features. The novel aspects of our approach include one of the first investigations into automated speech-centered HD detection and a focus on understanding the importance of modeling temporal variability for detecting HD.

# Immunomodulation Facilitates Survival of Human Stem Cell-Derived B-Cells at a Clinically Translatable Transplant Site (EGSR_13)


## Feiran Li, Lonnie Shea

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


Type 1 diabetes (T1D), which affects an estimated 3 million Americans, is an autoimmune disease involving a progressive destruction of pancreatic islet clusters, leading to loss of insulin production and secretion. The standard treatments of T1D, consisting of a life-long administration of exogenous insulin, either by daily insulin injections or an insulin pump, are often associated with debilitating hypoglycemic episodes due to inaccuracy. Allogeneic islet transplantation has led to the transient reversal of diabetes, but the feasibility has been greatly challenged by the donor scarcity problem. We have developed poly (lactic-co-glycolic acid) (PLG) scaffolds for transplant at a clinically translatable site with human embryonic stem cells (hESC) as an unlimited source to deliver functional β-cells. However, the biomaterial scaffolds together with the seeded cells elicit an inflammatory response after transplanting due to infiltration of immune cells into the scaffolds. To reduce the inflammatory response and the resulting graft failure, dexamethasone has been delivered to improve islet survival by modifying the immunological environment around scaffolds. Systematic administration of dexamethasone (1mg/kg injected intraperitoneally for 7 consecutive days) has been performed to the streptozotocin-induced diabetic male NSG (NOD scid-gamma) immune-deficient mice received the seeded PLG scaffolds. A significantly higher human cell population and a significantly higher macrophage population were found in the group received dexamethasone compared to the control group (**Figure**). The increased M2, rather than M1 macrophage population, was found to be the inducers of SMAD7-mediated-β cell proliferation. M2 macrophages were found to release TGFβ1 to directly induce up-regulation of SMAD7, which was sufficient to promote β-cell proliferation in vivo. Studies are still ongoing to further facilitate the maturation and function of the transplanted embryonic stem cell-derived β-cells by biomaterial scaffolding and immunomodulation.



## Active Flow Control for Helicopter Rotor Vibration Reduction (EGSR_16)


### Ryan Patterson, Peretz Friedmann

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



A computational fluid dynamics (CFD) model is developed to determine the unsteady aerodynamic effects of active flow control implemented by combustion-powered actuation (COMPACT) on a two-dimensional airfoil. Previous work with COMPACT actuators employed pulsed-jet actuation at moderate to high angles of attack to control flow separation and dynamic stall. However, the focus of the present study is to implement actuation in the moderate to low angle of attack range suitable for helicopter rotor vibration control. At low angles of attack, the effect of actuation on the sectional aerodynamic forces of the airfoil diminishes. Therefore, modifications to the COMPACT actuator configuration are considered to enhance the actuation authority for the relevant operating range. Modifications include placing a ramp on the airfoil upstream of the actuator and relocating the actuator near the airfoil trailing edge. These are considered using both CFD simulations and wind tunnel experiments, which are compared to validate the CFD model. Finally, a surrogate-based reduced-order modeling technique is described to address the high computational cost of the CFD simulations. The reduced-order model is used to accurately reproduce full-order CFD results for the unsteady changes in lift, moment, and drag due pulsed actuation on a static airfoil. Furthermore, the results show that the reduced-order model represents a feasible method for representing the unsteady aerodynamic effects of COMPACT actuation. This will be refined in future work and implemented in a comprehensive aeroelastic code for helicopter rotor vibration reduction.

# Patterns of Engagement: Engineering Student Interactions with Stakeholders in Capstone Design Projects (EGSR_18)


## R. P. Loweth[1], S. R. Daly[1], K. H. Sienko[1,2], A. B. Hortop[1], E. A. Strehl[2]

[1]*Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI*

[2]*Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI*



Unlike traditional engineering coursework, engineering design problems are inherently ill-structured and require practitioners to first define their problem before working towards a solution. Successful design outcomes involve a balance of both technical proficiency and a deep understanding of stakeholder and contextual needs. To uncover these needs, engineers must be able to communicate across disciplinary boundaries and consider the broader context of the design. Previous literature has shown that many engineering students vary substantially in how they think about and conduct stakeholder interactions. However, the factors which drive this variation have not been studied in detail. This study sought to address this gap by exploring how mechanical engineering students in a capstone design course engaged with stakeholders while working on user-centered projects.

Seventeen students across 6 different design teams participated in semi-structured interviews and submitted recordings of stakeholder meetings. These recordings were analyzed for communicative actions representing specific interactions between students and stakeholders. Communicative actions were then thematically grouped into 22 specific behaviors, divided evenly between techniques and challenges, to allow for comparison across teams.

Student meeting behaviors fell into three main categories: structural, exploratory, and multi-perspective. Structural behaviors focused on meeting organization and basic data collection. Exploratory behaviors involved deep investigation of the stakeholder’s experiences. Finally, multi-perspective behaviors established common ground between designer and stakeholder viewpoints on design activities. Students generally exhibited the structural and exploratory techniques taught in their course, although many teams encountered difficulties articulating questions and opportunistically following up on responses. However, substantial variation existed across teams. One team exhibited an unusually high frequency of both multi-perspective techniques and communicative actions for building relationships. This team also regularly met with their stakeholders throughout the project and exhibited few challenges exploring stakeholder experiences. In comparison, three teams rarely met with stakeholders and rarely exhibited non-structural techniques. Finally, two teams demonstrated an intermediate approach in that they frequently met with stakeholders and collected detailed information but exhibited few multi-perspective behaviors and rarely involved stakeholders in design decisions. The results illustrate distinct behaviors exhibited by students when interacting with stakeholders in authentic design situations, as well as characteristic project-level patterns of engagement which closely relate to different behavioral categories.

# Gaussian Mixture Model Framework for Classification of Venous Thrombus Composition (EGSR_19)

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Deep vein thrombosis (DVT), defined as clotting of blood in a deep vein, is the third most common cardiovascular disease in the world. The standard treatment for DVT involves using anticoagulants to stop the progression of the thrombotic process. Despite great success in preventing acute complications, this treatment is far from optimal in part because it relies on the body's natural fibrinolytic process to break up the clot. Therapies that promote fibrinolysis are only effective on an acute thrombus because its composition changes over time as the disease progresses to vein wall scarring, known as fibrosis. Currently there are no methods available to determine thrombus composition (and from it, thrombus age), which could be used to choose the optimal treatment for the patient. Our objective is to develop a probabilistic clustering model to determine venous thrombus composition from magnetic resonance imaging (MRI).

Obtaining human thrombus samples from a living patient is not possible, thus a well-established mouse model was used in this study. Following disease induction, mice were imaged on a 7 Tesla MRI, and thrombus tissue was harvested immediately following imaging to determine composition by histology, used as the ground truth for classifying MRI data. A Gaussian Mixture Model (GMM) was used for probabilistic clustering of T1-, T2-, and T2*-weighted MRI. The model was trained on 275 image sets from days 2, 6, and 14 post thrombus induction. An Akaike information criterion curve was used to determine that 3 clusters provided the highest relative quality while avoiding overfitting the model.

Thrombus composition varied spatially and temporally. As shown in Figure 1, a correlation is evident between the GMM tissue map and corresponding histology. The green tissue class corresponds to unorganized thrombus, rich in platelets and red blood cells and is most prevalent at day 2 (17±2% day 2 vs. 7±1% day 14, $p<0.01$). Regions classified with the blue tissue class mirrored fibrin-rich regions, most prevalent at day 6 (75±2% day 6 vs. 47±5% day 2, $p<0.0001$, and 58±5% day 14, $p<0.05$). Similarly, the red tissue classification corresponds to tightly packed red blood cells at day 2. These cells release iron as they die, suppressing this signal at day 6 before they are replaced by monocytes which are most abundant at day 14 (minimum at day 6 with 12±2% vs. 37±4% day 2, $p<0.001$ and 31±5% day 14, $p<.01$). In conclusion, the GMM framework results provide a novel approach to study thrombus composition. This approach could eventually be used clinically to provide patient-specific treatment planning for DVT. Future work will test the model in different treatment conditions and investigate the role of blood flow on thrombus composition.

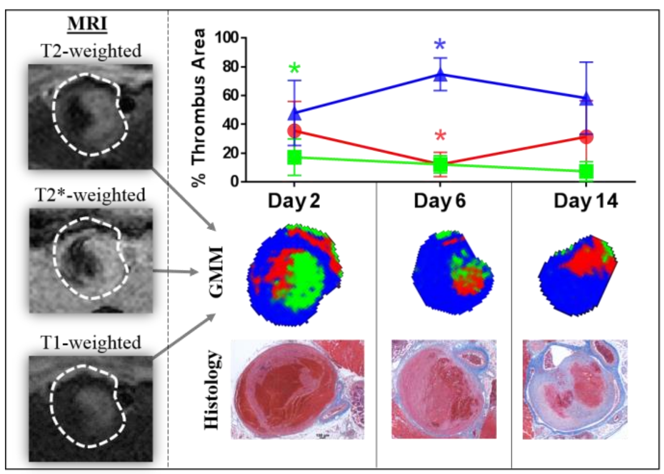


**Figure 1.** Representative MR images used to create a GMM tissue map, with the corresponding histology stained for Masson's trichrome. Percent thrombus for each tissue class is shown for each time point, mean ± standard deviation, n=55 images per group. * denotes *p<0.05* compared to other days of the same tissue class.

# Mood State Prediction for Individuals with Bipolar Disorder (EGSR_20)


## Katie Matton, Emily Mower Provost

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Bipolar disorder (BP) is a psychiatric disease that causes pathological mood swings, which fluctuate between periods of mania and depression. Its consequences can be devastating: individuals with BP have higher rates of social isolation, unemployment, and suicide than the healthy population. Moreover, the effectiveness of care for patients with BP is constrained by the lack of passive and objective tools available to clinicians for mood monitoring. Given that aberrations in speech patterns are a clinically recognized symptom of BP, automatic speech analysis offers a potential solution. The efficacy of applying acoustic analysis to detect mood states has been demonstrated by existing research. However, additional work is needed to improve task performance, and these methods, by focusing solely on *how* language is spoken, ignore a piece of critical information: the content and structure of *what* is said. Thus, in this work, we investigate the utility of linguistic features in classifying mania and depression.

Our analysis is conducted on the PRIORI dataset, a collection of phone conversations from individuals with BP. As part of the data collection process, each participant was provided with a smartphone that recorded their side of all calls made over a period of 6-12 months. In addition to these *personal* calls, the dataset includes weekly *assessment* calls for each participant, which are calls in which a clinician administers mania and depression severity tests. The purpose of the assessment calls is to assess symptom severity and they therefore contain more information relevant to mood than the personal calls, so we focus solely on them for this initial investigation.

We transcribe the calls using an Automatic Speech Recognition (ASR) system built using the Kaldi speech recognition toolkit. However, ASR transcripts are imperfect. This necessitates the identification of speech measurements that are robust to errors in transcription, which are present even in state-of-the-art ASR systems.

We analyzed over 200 features related to different linguistic aspects of speech, including the presence of affective content and salient words, part of speech usage, lexical complexity, coherency, and repetitiveness. We implement these measures using word embeddings, speech graph analytics, and the Linguistic Inquiry and Word Count (LIWC) toolkit, a resource for identifying psychologically meaningful content in text. The results of Mann-Whitney U tests with the application of a Bonferroni correction revealed that 52 features were significant in comparing depressed and euthymic (healthy) groups and 33 were significant in comparing manic and euthymic groups (for all features: $p < .0004$).

In this work, we focused exclusively on depression classification due to the relative rarity of mania within our sample. We detected depressive episodes, defined based on scores on clinical scales, using a Naïve Bayes model trained using a subject-independent framework. We evaluated performance using unweighted average recall (UAR) (chance is 0.5). We achieved a UAR of .681, which is comparable to previously published acoustic results on this dataset (.691 UAR).

Our results demonstrate that linguistic features can be effectively used for depression classification with performance comparable to models based on acoustic analysis. Our future work will examine the performance of models that incorporate both linguistic and acoustic information and will focus on detecting mood from the personal calls, which is a more difficult, but meaningful task due to their naturally occurring, unstructured nature.

## A Semianalytical Solution for Rarefaction-Driven Fluid Interfaces (EGSR_22)


### Michael Wadas, Eric Johnsen

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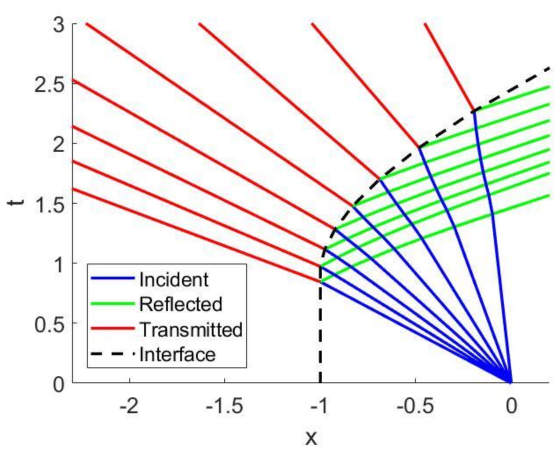
The instabilities generated when a wave passes through a fluid interface have important implications in many contexts ranging from therapeutic ultrasound (TUS) to inertial confinement fusion (ICF) to supernovae. In TUS, the instability-driven aspherical implosion of cavitation bubbles in biological tissues causes highly localized cellular damage that can enable non-invasive cancer treatment and a variety of other medical applications, though the precise implosion mechanisms are, at best, poorly understood. In ICF, hydrodynamic instabilities disrupt the interface separating the central hot spot from surrounding fusion fuel, inhibiting the high levels of compression required to initiate a sustained nuclear reaction. These same instabilities form during supernovae immediately following stellar core collapse and are responsible for populating the universe with heavy elements from deep within the centers of stars. Though the scales of these phenomena span over twenty orders of magnitude, they are united by the underlying physics governing interfacial hydrodynamic instabilities. A deeper understanding of these dynamics could lead to novel cancer treatments, advancements in fusion-based energy, and new theories aimed at quantifying the composition of galaxies.

Two key parameters governing the growth of interfacial hydrodynamic instabilities are the time-varying interface acceleration and Atwood number, a nondimensional representation of the density jump across an interface. This work presents a novel method for determining a semianalytical solution of an unstable one-dimensional fluid interface subject to the passage of a rarefaction wave. From this solution, the acceleration and Atwood number directly follow. The method makes use of a mathematical technique for solving partial differential equations called the method of characteristics. The novelty of this approach is the treatment of the boundary conditions at the interface. While a typical method of characteristics solution may be constructed using a prescribed velocity boundary condition for a problem involving a wave interacting with a surface, this approach utilizes a dynamic boundary condition that comes from the exact solution of a widely studied flow problem known as the Riemann problem. The velocity given by the Riemann solution is used to incrementally advance the position of the interface until it meets the next incoming portion of the impinging wave. At this point, the Riemann problem is again solved with the updated flow conditions. In this piecewise manner, the kinematic history of the interface is determined which, upon differentiation, immediately yields the acceleration as a function of time. Because this method also enables the calculation of the density on either side of the interface, the solution for the Atwood number as a function of time is also obtained. To the author's knowledge, such a solution was previously attainable only via numerical simulation. An example of the solution of a rarefaction wave impinging on a fluid interface obtained using this method can be seen in the figure. Note the nontrivial motion of the interface (dashed black line) and the solution of the nonsimple region where the incident wave interacts nonlinearly with the reflected wave. This technique has been verified through comparison with one-dimensional high-order numerical simulations.



# Wearable and Collective Sensing Framework to Detect the Elderly's Environmental Barriers (EGSR_23)


## Gaang Lee[1], Byungjoo Choi[2], Houtan Jebelli[1], Changbum Ahn[1], SangHyun Lee[1]

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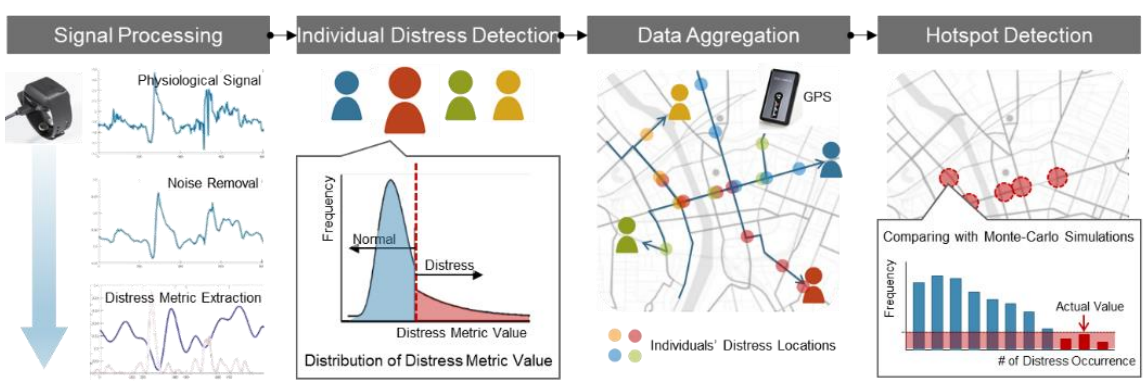
As U.S. Population is aging rapidly, the elderly's mobility has become critical to not only their individual wellbeing, but also the prosperity of our society. However, the elderly's mobility remains limited by various types of environmental barriers (e.g., cracked sidewalks and steep stairs) in the current built-environment. To detect these environmental barriers, wearable-type (e.g., a wristband) physiological sensors (e.g., Electrodermal Activity sensor) that measure people's distress responses to the barriers have been introduced. Despite their immense potential, it is still challenging to distinguish distress caused by environmental barriers from one by other distress stimuli (e.g., personal emotions and mental fatigue) because physiological signals indicate only the occurrence of distress, not its cause. To overcome this knowledge gap, this research proposes a wearable and collective sensing framework and tests its feasibility. Unlike a person's distress, collectively sensed distress can be indicative of environmental barriers because environmental barriers would commonly cause distress across multiple people who experience the barriers.

This study first extracts a distress metric from physiological signals using signal processing techniques (e.g., filtering, decomposition, and segmentation). The threshold estimation is used to detect occurrence of individual distress. Then, multiple people's distress is spatiotemporally integrated based on their collected locations and time. Distress hotspots (i.e., locations where collective distress is observed) are identified by comparing the actual distress with random distribution generated by Monte Carlo simulation considering characteristics of each subject. The proposed framework is validated using 20 elderly subjects' physiological and location data collected from their daily life. The distress hotspots detected from the proposed framework were compared with locations of environmental barriers identified by a site survey on the same area. The result showed that the pro-posed framework can accurately detect the environmental barriers in the site. The findings contribute to the use of wearable and collective sensing to measure people's stressful interaction with environmental factors, which is essential to detect and address the elderly's environmental barriers for their mobility.



## Three Dimensional Characterization of Short Fatigue Crack Growth in Rare-Earth Magnesium Alloys (EGSR_25)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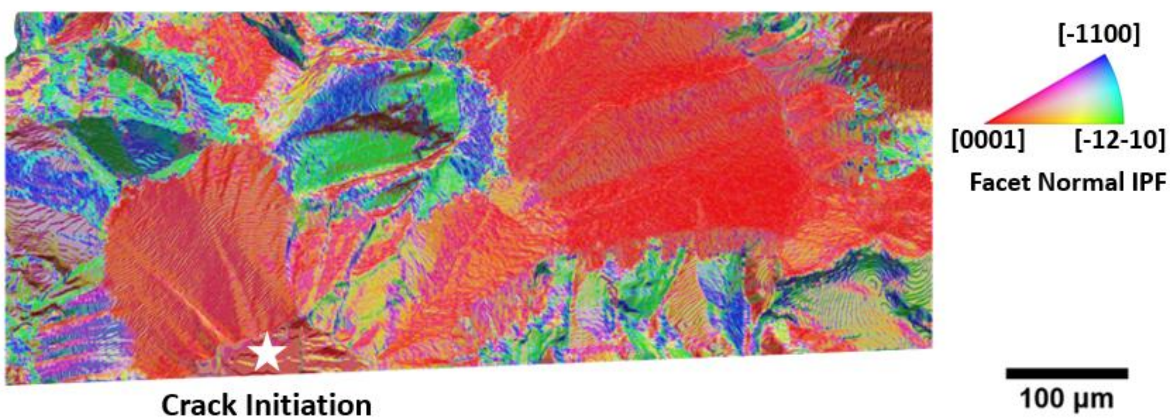
Magnesium alloys show promise for a variety of structural applications due to their high specific strength and low density, providing significant weight reduction and decreased environmental impact in transportation industries. To accelerate integration of magnesium, the Predictive Integrated Structural Materials Science (PRISMS) Center is developing simulation tools for fatigue deformation behavior, and to accurately model fatigue it is necessary to develop a greater understanding of the mechanistic phenomena involved in short crack growth. To this end, the three dimensional crystallographic crack path during very-high-cycle fatigue of magnesium alloy WE43 was investigated utilizing High Energy X-Ray Diffraction Microscopy (HEDM) at the Argonne Advanced Photon Source. Coupled far-field diffraction, near-field diffraction, x-ray computed tomography, and post-mortem electron microscopy of the crack initiation and short crack growth regions across the fracture surface provide detailed insights into local sub-surface orientation and crack growth rates. Initial crack growth is found to preferentially occur across basal aligned facets, followed by varied intragranular and intergranular propagation. Exposed fracture surface grain boundaries exhibit a wide angular misorientation spread across the high angle regime, and bulk short crack path tortuosity is found to vary across samples tested under similar conditions.

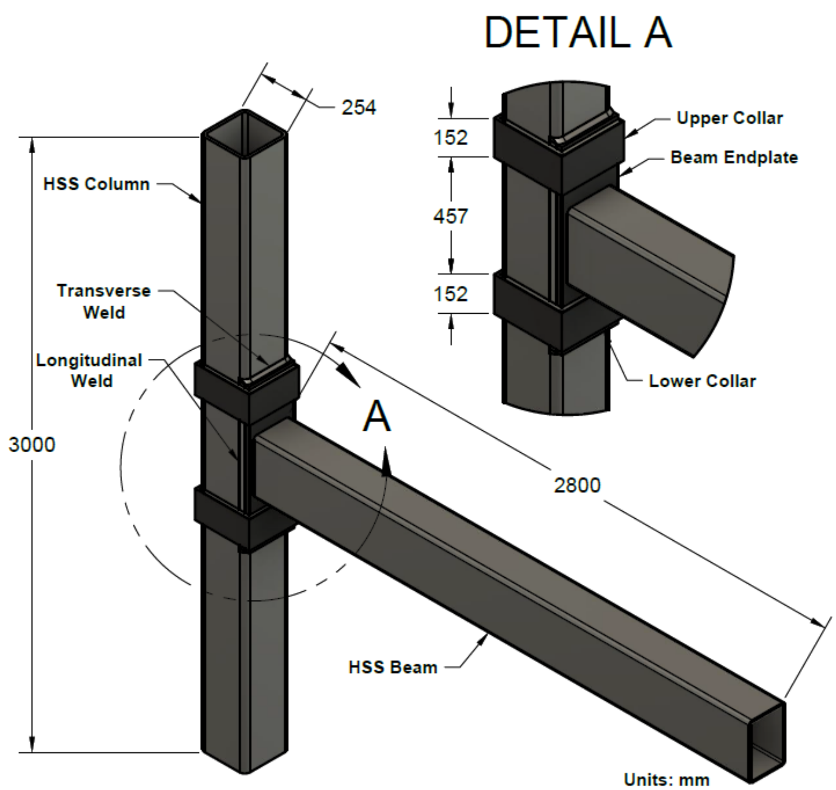
# Experimental and Computational Testing of Tube-Based Seismic Collar Connections under Cyclic Loads (EGSR_26)


## C. Flores Carreras, K. Arnson, D. Wei, J. McCormick

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


Connections for low-rise seismic moment frames solely utilizing hollow structural section (HSS) members have been shown to be viable allowing for the beneficial properties of HSS members to be utilized in seismic applications. These connections often require additional reinforcing plates, such as through-plates or external diaphragm plates, in order to ensure their performance meets current seismic design provisions. The addition of these reinforcing plates can lead to extensive field welding where quality control of the weld can be difficult. To address this problem, a collar connection concept is conceived to reduce the amount of field welding that is necessary. Two full-size tube-based collar connections are tested experimentally under large cyclic loads to understand their behavior and seismic performance. Both connections are shown to be able to meet current seismic design requirements.

A finite element model is calibrated and validated against the experimental tests to further explore the tube-based collar connection's behavior with respect to its weld configuration and beam endplate thickness. The findings show the need for a longitudinal groove weld between the beam endplate and HSS column in order to ensure a balanced connection design, while a transverse weld between the end of the beam endplate and HSS column has very little influence on the connection behavior. The thickness of the beam endplate can dictate the flow of forces through the connection. Overall, the tube-based collar connection is shown viable for seismic moment frame systems.



# Hysteresis and “Arrow of Time” in the Evolution of Grain Boundaries during Thermal Cycling (EGSR_27)


## Zhitong Bai, Yue Fan

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


Interfaces are ubiquitous in a broad range of modern material systems and are responsible for many of the magnetic, electrical, thermal, and mechanical properties. Grain boundary (GB) is a particularly important interface system, because: (i) most engineering materials are polycrystalline in nature; (ii) the bulk properties of polycrystalline materials are closely related with the structure of grain boundaries. The present study aims to obtain a fundamental knowledge on GBs in structural materials, and establish a robust structure-property relationship to predict their performance under complex thermo-mechanical conditions.

As an active area, GBs have been extensively studied over the past several decades and people’s understanding has evolved significantly. The main focus of early studies has been placed on the GBs’ static (i.e. 0K) structures and associated energies. More recent studies show a significant rise of complexity in GBs. In addition, the temperature effect has also drawn much attention as it plays a critical role in determining GBs’ structures and properties, such as the phenomena of roughening transition, phase transformation, and non-Arrhenius diffusion, etc. However, a predictive description on the evolution and structure-property relationship of GBs is still lacking because of their disordered atomic structures and non-equilibrium nature.

In this study, we plan to employ molecular dynamics (MD) method to investigate the response of GBs in Cu during thermal cycling, and employ the PEL sampling algorithm, activation relaxation technique (ART), to probe the variation of IS during such process. In our preliminary studies on <100> symmetric tilt grain boundaries (STGBs), by tracking the change of IS energy during heating/cooling loops, a universal hysteresis phenomenon has been observed for the entire group of <100> STGBs in Cu. In other words, the GB’s properties are not only dependent on surrounding temperature, but also very sensitive to its processing history. Meanwhile, we demonstrate that the time derivatives of GBs’ energy are always positive in some parameter space but negative in some other space. Therefore, the map of inherent structure energy with respect to the temperature can be divided into rejuvenating and ageing regimes, which enables a predictive understanding on the behaviors of GBs under arbitrary thermal protocols, including both regular and truncated thermal cycling. By further examining the underlying PEL of the GBs’ IS by ART method, we are able to quantify the significant shift of activation energy spectrum at various thermal stages, which provide direct supporting evidence to the previous observed non-Arrhenius diffusion and temperature-dependent activation barriers. The reason of exploring the activation energy spectrum of the inherent structure is that the system activation energy is closely related with the structure properties such as mobility and diffusion. The hereby obtained results are strongly reminiscent of the non-equilibrium features in metallic glasses, which therefore might open a new avenue for developing a glass-like theory to quantitatively describe the GB’s structure-property relationship in the future.

# Comparing Idea Generation Outcomes from Crowdsourcing and Individual Creativity (EGSR_28)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The need for innovation is steadily increasing, and there is an increasing interest in the creative abilities of engineers for these innovations. Given these trends, many companies are trying to get new ideas, one of which is "crowdsourcing" approach. Crowdsourcing refers to the opening task by a large number of people. Ideas and information from crowdsourcing are almost unlimited and much cheaper and faster, leading that engineers can use the crowdsourcing data to gain inspiration for their concept generation through direct and active feedback from users. Given the vast accessibility features of the information that crowdsourcing has, it also has the advantage of being able to access various perspectives of people. Existing studies argued that the better quality of ideas occurs when new ideas are combined with existing ideas. Therefore, when people with more diverse and more kinds of knowledge are gathered to produce ideas, they can generate higher quality ideas by recombining and utilizing existing information. Thus, considering the characteristics of the crowdsourcing platform, it seems reasonable that the high accessibility of various information related to the idea generation process can improve the quality of ideas. However, previous studies also showed that the existence of relevant information can give a negative effect in the idea generation process, which is design fixation. Fixation refers to a phenomenon in which people tend to fix on the characteristics of the examples given earlier and this affects the generation of less unique ideas. Previous research showed that exchanging ideas reduced the number of domains in the idea, and ideas converged similarly, suggesting that exchanging ideas reduced the breadth of ideas in the idea generation process since people are unintentionally and unconsciously caught up in existing information. Taken together, the characteristics of crowdsourcing platforms can positively or negatively affect the idea diversity. Therefore, based on these two different possibilities, this research analyzed the characteristics of the crowdsourced ideas from OpenIDEO, one of the crowdsourcing design platforms and investigated the effectiveness of the quality of ideas by comparing with independently generated ideas from individuals.

Our crowdsourcing data were obtained from OpenIDEO website, an open design online platform. We analyzed the ideas proposed in the 'food waste' challenge which was launched from Jun to September 2016. More than 20,000 people from more than 100 different nationalities participated in the challenge over three months and we analyzed a total of 450 ideas proposed by participants in their initial idea generation phrase. Individual data were collected from twenty students of the University of Michigan and each student was asked to generate 20 ideas about the same food waste challenge independently. We analyzed a total of 400 ideas from individuals and 450 ideas from crowdsourcing website and compared them. In order to identify idea diversity, we categorized ideas into 12 stages by food waste cycle and investigated how distributed those ideas were. Then we calculated the frequency of ideas included in each category and how many percent of the ideas they took. Unlike what we expected, the OpenIDEO's ideas were concentrated only in two categories (Home storage: 28%; Meal planning: 21%), while students' ideas were spread across the four different categories (Store: 13%; Meal Planning 13%; Leftover: 13%; Disposal: 19%). These results suggest that engineers are encouraged to generate their own ideas independently first, then share ideas later since sharing ideas in early idea generation stage can influence possibly the design fixation.

# Designing and Implementing the Downstream Processing for Anaerobic Production of Medium-Chain Carboxylic Acids (EGSR_30)

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Several biotechnological processes to treat organic waste streams are gaining increasing attention in contrast to conventional and unsustainable methods like landfill disposal or incineration. One such approach is the production of medium-chain carboxylic acids (MCCAs) from organic waste streams by using anaerobic fermentation technology. Under the right operational conditions a mixed microbial culture can perform chain elongation to convert short-chain carboxylic acids (SCCAs) into medium-chain carboxylic acids (MCCAs). MCCAs are saturated fatty acids with six to twelve carbons that can be used in a range of applications like animal feed additives, antimicrobials, fragrances, pharmaceuticals, and as precursors for liquid fuels. This addresses the increasing worldwide demand for crude oil and oil-related products while simultaneously coping with the rising amount of organic waste.

A bench-scale semi-continuous anaerobic bioreactor system is currently being operated with the goal of producing MCCAs in a two phase setup. In the first phase bioreactor, food waste is being fermented and converted into SCCAs while in the second bioreactor, these SCCAs are elongated into MCCAs by addition of ethanol-rich brewery waste from a local brewery. However, above a certain concentration MCCAs become toxic to the chain elongating microbial community thus hindering growth and the production of the desired chemicals, i.e. MCCAs. It has been observed that the performance of the current second phase reactor is not sufficient and the inhibitory effect of MCCAs is likely to be one of the reasons.

This work focuses on the design and development of an extraction unit for continuous removal and recovery of MCCAs via membrane based liquid-liquid extraction (pertraction). This allows for the MCCAs to be converted into useful products while also preventing the inhibitory effect of these acids on the microbiomes.

The extraction unit consist of two Liqui-cel 2.5X8, X40 (3M, Charlotte, NC, USA) hydrophobic hollow fiber membrane contactors with a surface area of $1.4m^2$. Membrane contactors bring two liquids into contact without mixing and are replacing conventional liquid-liquid extraction units because of their lower cost, smaller size, simple installation, and high surface area for greater extraction efficiency. In the first forward unit the acidic reactor effluent (pH 5.5), consisting of a mixture of SCCAs and MCCAs, is brought into contact with light mineral oil (solvent) and trioctylphospine oxide (TOPO, extractant). This mixture preferentially extracts the more hydrophobic medium-chain acids over short-chain acids which can then be recirculated and further elongated in the bioreactor. In the second backward membrane contactor, an alkaline (pH 9) stripping solution back-extracts the MCCAs from the solvent. The concentration of undissociated acids is very low in the stripping solution due to its high pH (pKa of MCCAs ~4.85). This creates a concentration gradient between the two liquids that serves as the driving force for mass transfer. Due to the hydrophobic nature of MCCAs, phase separation occurs above a certain concentration, allowing for easy partitioning of the aqueous and organic phase. It is important to optimize the extraction process to achieve the highest transfer rate of MCCAs from the reactor to the stripping solution. This includes optimizing the flow rates of the three separate fluids. The extraction efficiency is evaluated by calculating the mass transfer coefficient k [mm/d] that indicates the rate of first-order mass transfer. The ultimate goal is to achieve an economically feasible and environmentally sustainable production of MCCAs that has the potential to be implemented on a large scale.

# Postural Instability in Autonomous Vehicles Following Front-Seat Passenger Exposure (EGSR_31)


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One unaddressed, possible safety concern for autonomous vehicles is postural instability among passengers following a drive, which may induce motion sickness and thereby potentially increase the risk during post-exposure activities. Prior research has shown that exposure to inertial motion, or even the perception of motion, contributes to a temporary increase in postural instability. Although driving simulations can provide accurate visual and auditory stimuli, the postural constraints that act on passengers can differ significantly. Therefore, the goal of this study was to characterize the effects of riding in the front-seat of an actual vehicle on standing balance.

Forty-six adults (20 males, 26 females; aged 18 to 78 years (41.02 ± 20.68 years)) were driven on scripted routes in M-City. Participants were randomly assigned to either a moderate or low acceleration driving group. Within each group, participants completed two 20-minute drives as front-seat passengers, one of which involved the simultaneous completion of a task consisting of a tablet-based questionnaire that evaluated basic reading comprehension, visual search, pattern logic, and spatial awareness skills.

Participants completed three 30-second repetitions of two balance exercises before and after each drive. The first exercise required participants to stand with feet in the tandem Romberg position on a firm surface with their eyes open (EO). The second exercise required participants to stand in the Romberg position on a foam surface with their eyes closed (EC). A smartphone-based inertial measurement unit was used to capture the trunk kinematics. Six parameters were derived from these data: root-mean-square (RMS) of angular position and velocity (A/P and M/L direction), the 95% elliptical area (EA), and the path length of the sway trajectory. Paired non-parametric tests were performed to detect significant pre-to-post postural changes using a significance level of 0.05.

In both exercises, post-drive RMS velocity in the A/P direction was significantly greater than pre-drive values across all drive conditions. However, path length and velocity in the M/L direction were significantly greater in every condition for only the EC exercise. Among drive conditions, the post-drive measurements of M/L RMS ($p<0.01$) and EA ($p<0.05$) in the moderate-task drive were significantly higher than their respective moderate-no task measurements in the EC exercise. In the EO exercise, A/P RMS ($p<0.01$) and path length ($p<0.05$) measurements were significantly higher in the low-task condition than the low-no task condition.

In short, exposure to these ecological driving conditions decreased postural stability regardless of acceleration and task. Future work should explore the relationship between vehicular induced motion sickness symptoms and postural instability, as well as test whether these effects translate to on-road traffic.

# Reaction Kinetics Analysis in a Solar Device for Wastewater Treatment (EGSR_32)


## Luisa Barrera, Rohini Bala Chandran

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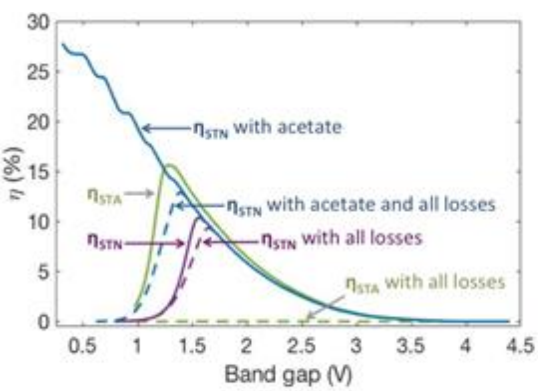
Excessive anthropogenic production of nitrogen fertilizers combined with rapid industrialization has disrupted the natural balance of the nitrogen cycle leading to increased concentrations of reactive-nitrogen species including nitrates ($NO_3^-$) and ammonium ($NH_4^+$) in groundwater, rivers and lakes. These nutrient imbalances can lead to health risks in human beings by causing methemoglobinemia in infants and may cause cancer in adults, as well as negatively impact the environment by causing acid rain and algal blooms. Municipal drinking water and wastewater facilities account for ~4% of the overall energy use in the United States, even though organic and reactive-nitrogen contaminants have unused stored energy.

In this work we propose a solar/photoelectrochemical approach to convert wastewater $NO_3^-$ to yield either nitrous oxide ($N_2O$) for energy recovery, or $NH_4^+$ as nutrient recovery (for fertilizer applications). We consider a batch-reactor with planar electrodes and an ion-exchange membrane that facilitates ion exchange while attenuating gas crossover. Incident sunlight is absorbed by a photoactive anode made of a semiconductor material to effect the oxidation of $H_2O$ or organic contaminants that are naturally present in wastewater streams. On the cathode surface, it is desired to selectively reduce $NO_3^-$ to either $N_2O$ or $NH_4^+$. Even though $N_2O$ is a potent greenhouse gas, reduction of $NO_3^-$ to $N_2O$ is expected to result in greater energy recovery than reduction to $NH_3$ as $N_2O$ has low aqueous solubility in comparison with $NH_3$ (0.023 M vs. 28 M at standard conditions and pH = 7).

To down-select semiconductor material band gaps and identify target oxidation and reduction reactions that maximize the device efficiency, we have developed a model that combines the current-voltage behavior of an ideal diode for the semiconductor, and Butler-Volmer kinetics for the electron-transfer reactions. This model applied detailed-balance equations for the diode and evaluated kinetic overpotentials considering state-of-the-art catalysts for the redox reactions. Ideal/upper limits for the solar energy conversion efficiencies of the proposed device were predicted. The tradeoffs in producing $NH_3$ in comparison to $N_2O$ are shown in Fig.1. We also considered the effects of energy losses due to ion migration (ohmic losses) and gas crossover losses from the catholyte to the anolyte. Fig. 1 shows that $NH_3$ production is at least 50% more efficient than $N_2O$ production without ohmic and crossover efficiency losses. The peak efficiency (15.6%) for $NH_3$ occurs at a slightly lower bandgap of 1.28 eV compared to 1.56 eV for $N_2O$ due to the differences in the electrocatalytic overpotentials. Ohmic losses, due to potential drop across the membrane, decrease the efficiencies in all cases. The high aqueous solubility of $NH_3$ results in large crossover losses compared to $N_2O$ and therefore when all losses are considered, $N_2O$ presents itself as a more viable end product. When acetate acts as an electron donor instead of water, the maximum solar-to-$N_2O$ efficiency keeps increasing with decreasing band-gap. This result is largely driven by net oxidation-reduction reaction becoming thermodynamically downhill for acetate oxidation ($E^0_{net}$ = 0.712 V vs. RHE) compared to water oxidation ($E^0_{net}$ = -0.395 V vs. RHE).



# Hyperspectral Absorption of Monolayer Crystals (EGSR_34)


## Claire Lu[1], Qiannan Wen[2], Mack Kira[1]

*[1]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*
*[2]Applied Physics Program, University of Michigan, Ann Arbor, MI*


Atomically thin semiconductor materials, monolayers, have been demonstrated to possess extraordinarily strong excitonic absorption features – more than 20% of light absorption per monolayer has been demonstrated. We propose to stack several monolayers to a one-dimensional crystal to achieve a nearly perfect absorption over Sun's emission spectrum, which could potentially improve the current solar-cell efficiency dramatically.

We solve the absorption properties of individual monolayers microscopically with the semiconductor Bloch equations (SBEs) under different conditions, and solve the light propagation through a monolayer stack self-consistently from the coupled SBEs and Maxwell's equations. Optimal crystal structures are deduced as a function of monolayer material parameters. The possibility of synthesizing these crystals are checked by a Monte Carlo method, to account for imperfections and their effects on device performance. Figure 1 shows a comparison of the hyperspectral absorption realized for InGaN-monolayer-based systems without (shaded area) and with (red line) disorder. This system shows over 90% absorption for 1.63 to 2.5eV spectral range even for slightly disordered systems. In summary, we show that monolayer stacking could yield intriguing applications.

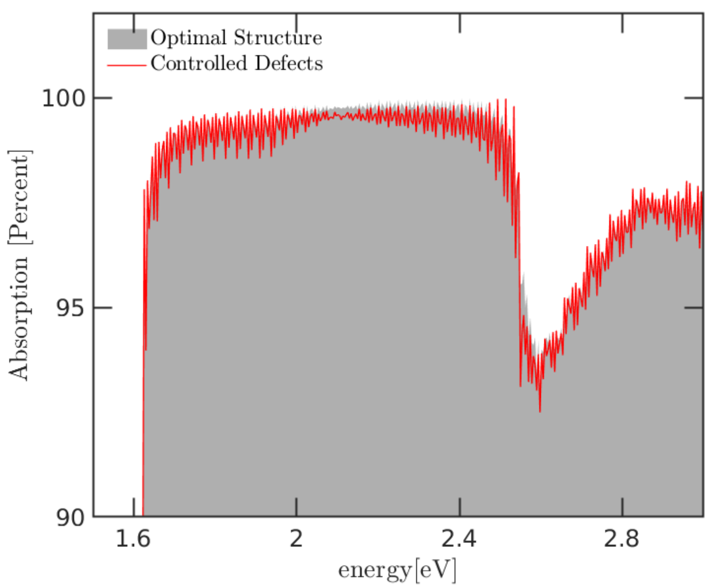



**Figure 1**

# Medium Chain Carboxylic Acid Recovery from Urban Waste Streams (EGSR_35)


## Brittany Colcord, Shilva Shrestha, Lutgarde Raskin

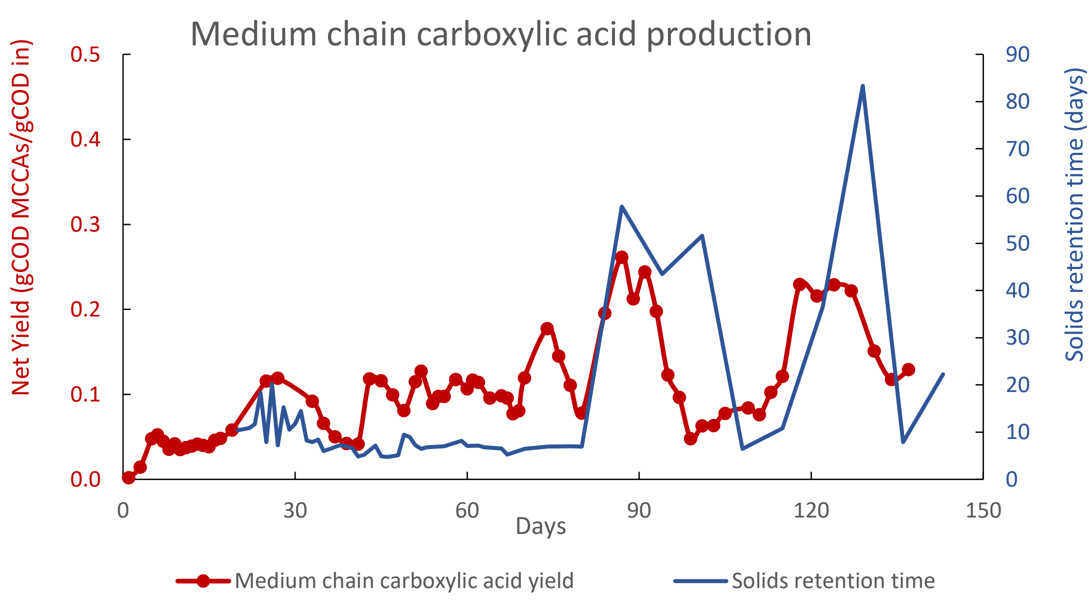
*Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI*


The recent boom in brewery operations has introduced unique challenges in waste disposal. Increased flowrates and high solids and organic concentrations often exceed treatment capacities of smaller municipalities, making brewery waste more expensive and difficult to treat. Solid brewery waste, along with other urban waste streams, like food waste, are sent to landfills to decompose, releasing methane into the atmosphere. But, these wastes are rich in biodegradable organics, which can provide valuable resources in recovery processes. By diverting organic waste streams from landfills, greenhouse gas emissions can be reduced and precious resources avoid entrapment. This research aims to optimize resource recovery from organic urban waste streams by harvesting medium chain carboxylic acids (MCCAs).

MCCAs are economically valuable byproducts of anaerobic digestion, commonly used in animal feed, pharmaceuticals, lubricants, and as precursors of biofuel production. MCCAs are fatty acids with a six to twelve carbon chain produced via chain elongation, a process in which ethanol provides a carbon source to elongate short chain carboxylic acids (C2-C5) .

A continuously-mixed semi-continuous anaerobic bioreactor, inoculated with rumen content from a cow's stomach, was used as the vessel to facilitate MCCA production. SCCAs were sourced from the permeate of an anaerobic bioreactor that ferments food waste, and brewery waste served as the ethanol source for chain elongation. The hydraulic and solids retention times were varied throughout operation to optimize reactor productivity, settling on a low hydraulic retention time (2-4 days) and an infinite solids retention time.

Process efficiency was quantified as yield (ratio of product to influent fed), expressed as chemical oxygen demand (COD). A maximum yield of 0.26 (g COD MCCA/g COD influent) was achieved at a net production of 5.6 g COD of MCCAs. The maximum yield was achieved at a longer solids retention time (see figure) and a decreased influent ethanol concentration. This correlation indicates that ethanol toxicity may be hindering reactor performance. Another concern is MCCA accumulation in the system, where the produced acids build up and toxify the environment for chain elongating microorganisms. The continuation of this research will include steps to extract MCCAs upon production, determine the optimal ethanol to SCCAs ratio, and alter operating conditions to increase yield. Ideally, this research can eventually be applied at a municipal level to sustainably treat urban waste streams, recover economically valuable resources, and reduce greenhouse gas emissions.



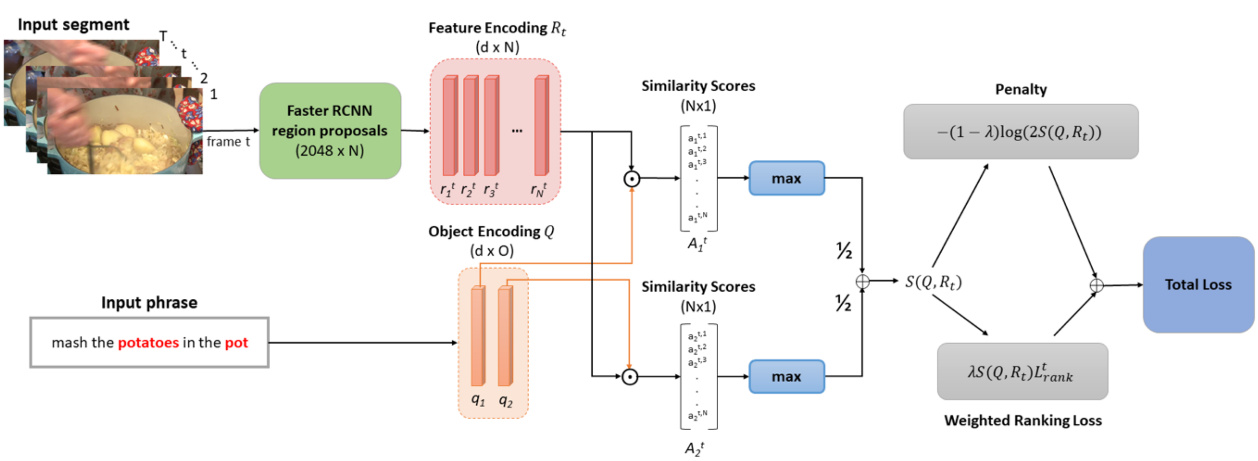
# Weakly-Supervised Video Object Grounding from Text by Loss Weighting and Object Interaction (EGSR_36)

**Luowei Zhou[1], Nathan Louis[2], Jason J. Corso[1,2]**

[1] *Robotics Institute, University of Michigan, Ann Arbor, MI*

[2] *Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*

We study weakly-supervised video object grounding: given a video segment and a corresponding descriptive sentence, the goal is to localize objects that are mentioned from the sentence in the video. Unlike fully-supervised methods, no object bounding boxes are available during training, but the set of possible objects to be grounded is known beforehand. Existing approaches in the image domain use Multiple Instance Learning (MIL) to ground objects by enforcing matches between visual and semantic features. With this technique, images are simply labeled as positive or negative instances of a present object. A naive extension of this approach to the video domain is to treat the entire video segment as a bag of spatial object proposals. However, an object existing sparsely across multiple frames might not be detected completely since successfully spotting it from one single frame would trigger a satisfactory match. To this end, we propagate the weak supervisory signal from the segment level to frames that likely contain the target object. First, we estimate the likelihood that the object is present in the frame. For a higher likelihood, we judge the matching quality primarily on the matching loss. For frames that are unlikely to contain the target objects, in the case of occlusion or off-screen objects, we use an alternative penalty loss. We also leverage the interactions among objects as a textual guide for the grounding. We evaluate our model on the newly- collected benchmark YouCook2-BoundingBox and show improvements over competitive baselines.



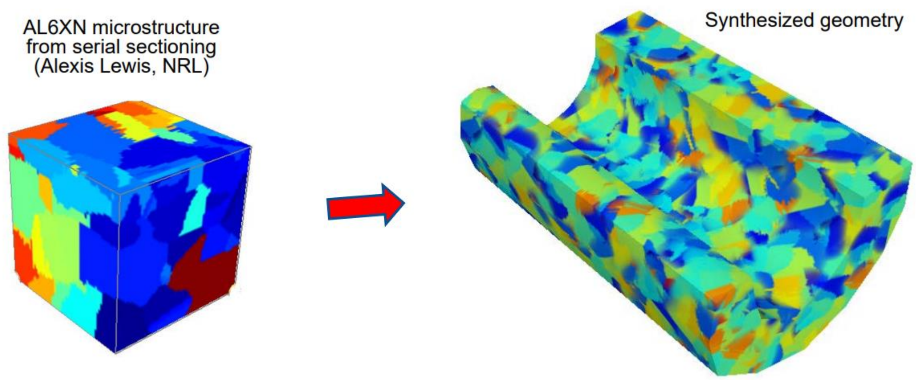
# Probabilistic Graph Theoretic Approaches for 3D Microstructure Reconstruction (EGSR_37)


## Iman Javaheri, Aaditya Lakshmanan, Veera Sundararaghavan

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



Measurement and analysis of microstructures is an important aspect of materials design and structural performance. Grain sizes, cell structures, and precipitate distributions affect the engineering properties as well as the performance of advanced materials in aerospace engineering. In this work, we present our progress on data-driven methods for microstructure reconstruction using Markov Random Fields. The algorithm reconstructs 3D models by matching slices at different voxels with the representative 2D micrographs. This code incorporates an optimization technique that ensures the patches from the 2D micrographs are meshed seamlessly together in the 3D reconstruction. We demonstrate that the method effectively models 3D features in the microstructure by considering the following three cases: (i) disperse spheres, (ii) anisotropic lamellar microstructure, and (iii) a polycrystal. The method is validated by comparing the point-probability-functions and 3D shape-moment-invariants of the synthesized images to the original 2D images.

## Classification of Transients (EGSR_39)


### Alvin Lee, David R. Dowling

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



Transient signals on the order of 100ms are often difficult to classify quickly in the presence of noise. In general, Human operators classify detected transients by listening and examining acoustical representations. However, due to many contacts and reverberation in noisy underwater environments, it takes a relatively long time to process each possible contact via human hearing. Therefore, automatic classification is needed to shorten the process time and improve accuracy.

In this work, we report on the classification of transient acoustic signals comparing effective features and classification methods. Here, five sounds represented by 24 samples each were used: balloon pop, hand clap, and metal-to-metal, plastic-to-plastic, and wood-to-wood impacts. The classification process was done in two stages. At the first stage, the metal and plastic sounds were separated from the other three using time-domain features such as zero crossing rate and short time energy, and spectral features such as frequency centroid, skewness and rolloff. The metal and plastic sounds were reliably classified because these sounds have obvious spectral characteristics. At the second stage, transients that could not classified due to similar spectral envelopes were classified by measuring the amplitude decay time of frequency amplitudes in the spectrogram. The K-nearest neighbor method was used as a classification method and 12 test and 12 training samples were used for each class. The result of the classification process showed a true-positive rate of 90% or more on transients except the 'clap' sound, which could only be classified with 50% of accuracy.

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# Probing the Charge Transfer Mechanism of Vanadium Redox Flow Batteries (EGSR_42)


## Harsh Agarwal, Jin-Xun Liu, Bryan Goldsmith, Nirala Singh

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


Energy demand is continuously increasing with the world's growing population and rapid improvement in the average standard of living. Fossil fuels are burned at an incredible rate to satisfy this growing energy demand, emitting 35 billion tons of $CO_2$ in 2017, emphasizing the need to shift towards other renewable energy sources like solar and wind. However, due to the intermittent nature of these renewable sources, there is a need to store their energy so that it can be used when necessary. Energy storage will also help in making the grid more reliable in case of sudden power fluctuations.

Vanadium redox flow batteries (VRFBs) are a promising means of storing renewable energy where electricity is stored and released by reducing or oxidizing vanadium ions in aqueous solvents. Though VRFBs have been tested on benchtop and at pilot scales, the cost remains the limiting factor for their widespread adoption. Increasing current densities without decreasing the energy storage efficiency is one way of reducing the cost which can be achieved by enhancing reaction rates. Incorporating electrocatalysts such as Bi, Ag, Sn onto carbon have been shown to increase the rate of the $V^{2+}/V^{3+}$ redox reaction (depicted below) at the negative electrode of VRFBs, but why these electrocatalysts improve the rate is still unclear. The lack of reaction mechanistic understanding makes designing better electrocatalysts extremely challenging. The aim of our work is to understand the mechanism of the $V^{2+}/V^{3+}$ redox reaction on metal surfaces, which will help us to determine the best electrocatalyst and increase the effectiveness of VRFBs to make them more commercially viable for energy storage.

$$V^{2+} \rightarrow V^{3+} + e^{-} \qquad\qquad E^{o} = -0.255\ vs\ SHE$$

One possible mechanism on carbon and metals involves the exchange of the vanadium ion (either adsorbed on the catalyst surface or not) with surface H as an intermediate step in the $V^{2+}/V^{3+}$ reduction or oxidation reaction. The H involved in the exchange is present as OH on carbon or adsorbed H atoms ($H_{ads}$) on metals. Our hypothesis is that the strength of the bound hydrogen will correlate with the electrocatalyst reaction rate, if $H_{ads}$ plays a role in the $V^{2+}/V^{3+}$ reaction, and catalysts that bind $H_{ads}$ weakly will most easily catalyze the reaction. For metals, the $H_{ads}$ binding strength is well known from DFT calculations and previous experimental measurements, but the reaction rate of $V^{2+}/V^{3+}$ directly on those metal surfaces (i.e., not supported on carbon) has not been measured, nor have their activation barriers, a parameter whose value is lowest on the most active electrocatalyst.

We measure the rate of $V^{2+}$ oxidation and $V^{3+}$ reduction by recording the steady state current as a function of applied potential on glassy carbon and compare them to metal films (e.g., Bi, Ag) that bind hydrogen weakly to test our hypothesis of $H_{ads}$ playing a critical role in the $V^{2+}/V^{3+}$ reaction rate. The results on glassy carbon show a dependency on fraction of $V^{3+}$ ions in solution, with no dependency on the total concentration of vanadium ($V^{2+}$ and $V^{3+}$) species in solution, indicating that the $V^{3+}$ ion might be getting adsorbed on the surface acting as a reaction intermediate, implying a catalytic effect and the importance of adsorbed species on reaction rate. We also show that the rate measurements are independent of the nature of the counter-ion ($Cl^-$ and $SO_4^{2-}$), highlighting that V ion complexes in aqueous solutions have similar orientation and d-orbital splitting with $Cl^-$ and $SO_4^{2-}$, as these factors determine the strength of interaction of coordinated complex with the electrode thereby affecting the charge transfer rate. By measuring the rate as a function of temperature (20°—40°C), we evaluate the activation barriers to compare different catalysts.

# Multipoint Airfoil and Wing Shape Optimization for Subsonic and Supersonic Regimes (EGSR_44)

## Marco Mangano, Joaquim R. R. A. Martins

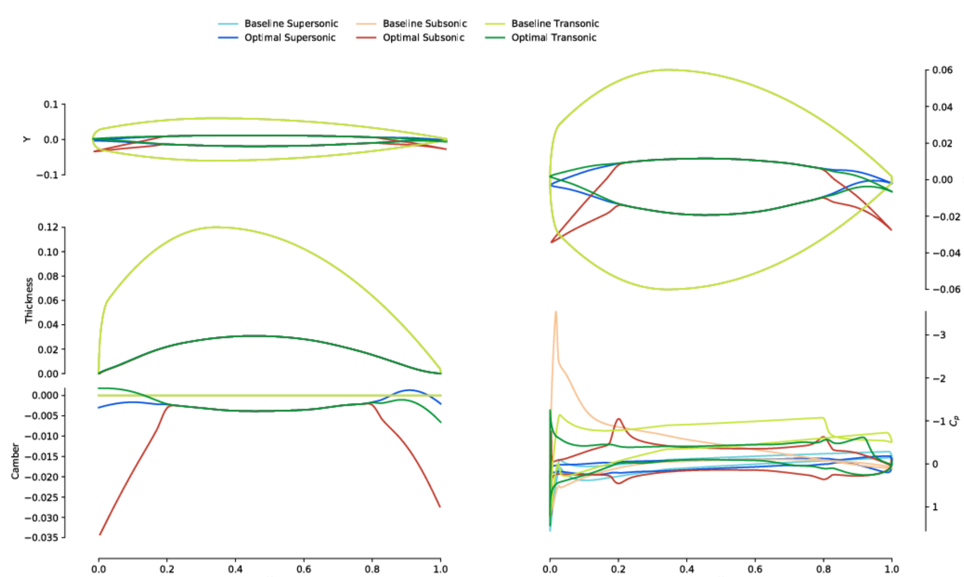
*Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI*

The second generation of supersonic civil transport has to match ambitious targets in terms of noise reduction and efficiency to become economically and environmentally viable. High-fidelity numerical optimization offers a powerful approach to address the complex trade-offs intrinsic to this novel configuration. Past and current research has proven the potential of supersonic aircraft shape optimization but lacks in deeper insight on final layouts.

This work partially fills the gap by extensively investigating RANS-based aerodynamic optimization of airfoils for both supersonic and subcritical conditions. We perform single and multi-point optimization to minimize the drag of wing sections over an ideal supersonic aircraft flight envelope and assess the influence of physical and numerical parameters on optimization accuracy and robustness. Leading and trailing edge morphing topology is introduced to improve the efficiency at transonic and subsonic flight speed by relaxing the trade-offs on clean shape optimization. Benefits in terms of drag reduction and trim requirements are quantified and benchmarked with fixed topology results.

The study is then extended to fixed-planform, full-wing cases, assessing the impact of 3D compressibility and viscosity effects on the optimal shape and introducing additional design variables such as twist and dihedral angle. Both low-sweep, low-aspect-ratio wing and oblique wing configuration are investigated. The outcome of this work will partially fill the gap in the current supersonic aerodynamic shape optimization literature and provide consistent reference data for future full-configuration, multidisciplinary optimization studies.

In the figure below, key features of a preliminary multipoint airfoil optimization study are reported, highlighting how leading and trailing edge deflection can be exploited to ensure good low-speed performance without compromising the optimal supersonic "biconvex" shape.



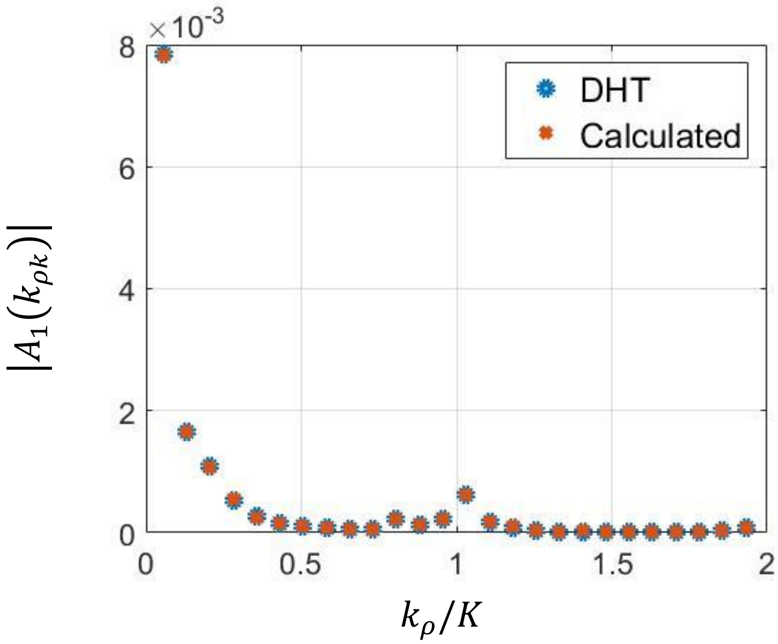
# Application of the Discrete Hankel Transform to Cylindrical Waveguides Structures (EGSR_45)


## Faris Alsolamy, Anthony Grbic

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


In this work, we apply the Discrete Hankel Transform (DHT) to solve electromagnetic problems that involve cylindrical waveguide structures. We demonstrate the DHT's use by deriving the modal wave matrix for inhomogeneous isotropic electrical sheet impedance inside cylindrical waveguide. The modal wave matrix is written in terms of the DHT transformation matrices which are known in closed-form. The modal wave matrix relates the forward and the backward modal coefficients below the sheet impedance to the forward and the backward modal coefficients above the sheet impedance. Having such matrix can be very helpful to realize certain bianisotropic boundary conditions, by simply three cascaded isotropic electrical sheets.

In the figure below, the modal wave matrix has been verified by comparing the magnitude of the forward modal coefficients evaluated by two methods: Modal wave matrix (labeled DHT), and the standard method which is the modes orthogonality (labeled: calculated).

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# Using Control Synthesis to Generate Corner Cases: A Case Study on Autonomous Driving (EGSR_46)

**G. Chou[1], Y. E. Sahin[1], L. Yang[1], K. J. Rutledge[1], P. Nilsson[2], and N. Ozay[1]**

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

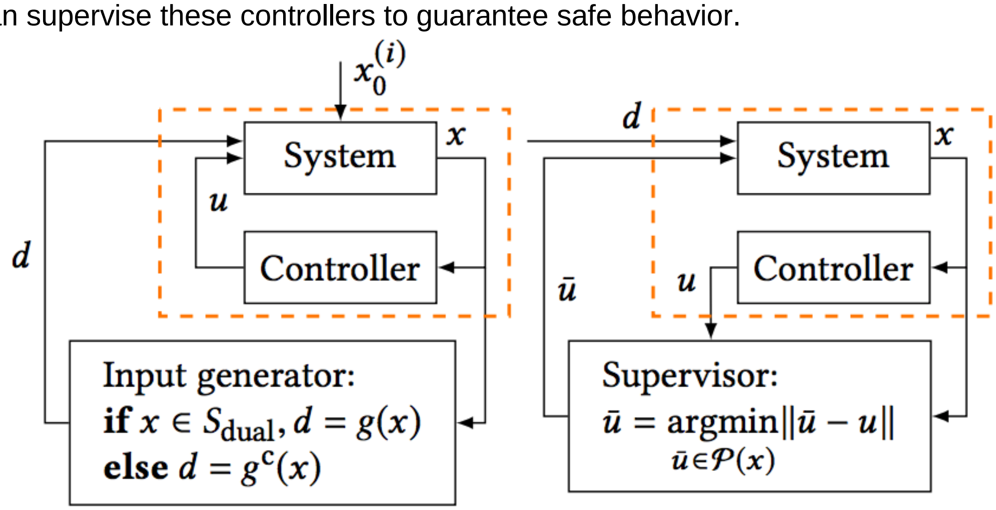
[2]*Department of Electrical Engineering, California Institute of Technology, Pasadena, CA*

As complex autonomous driving systems start to be deployed in the real world, the need for methods that can detect faults in the self-driving software has become increasingly important. The process of generating difficult test cases which will cause the software to fail is known as falsification. In this work, we employ correct-by-construction control synthesis - in particular, controlled invariant set computations - to falsify self-driving software. A controlled invariant set describes the set of system configurations (in this case, the car orientation and velocity) from which there exists a control (steering/throttle command) to ensure the system behaves safely.

We show that if it is possible to compute a “large enough" controlled invariant set for either the true system model or some simplification of the system model, we can generate initial car configurations which falsify the software by sampling such configurations from the boundary of this controlled invariant set. Moreover, we show that even if the self-driving controller would crash under these initial conditions, we can use controls generated from the controlled invariant set to override (**supervise**) the self-driving controller to ensure safe system operation.

In addition to finding initial conditions which can falsify the controller during the initial transient, we use solutions from a dual game - a reachability game for the safety specification - to find road profiles (**disturbance inputs**) which can falsify the self-driving software after the initial transient. We also propose optimization-based heuristics for generating road profiles when the dual game has no solution. To demonstrate the proposed ideas, we consider case studies from basic autonomous driving functionality, in particular, adaptive cruise control and lane keeping.

We show how our proposed technique can be used to find interesting falsifying trajectories for classical control designs like proportional controllers, proportional integral controllers and model predictive controllers, as well as an open source real-world autonomous driving package. We also show we can supervise these controllers to guarantee safe behavior.



# Heat Treatment Effects on Precipitation in Irradiated HT9 Steel (EGSR_47)


## Theresa Mary K Green[1], Li He[2], Lingfeng He[3], Brandon Miller[3], Todd Allen[1]

*[1]Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI*
*[2]Department of Nuclear Engineering and Engineering Physics, University of Wisconsin-Madison, Madison, WI*
*[3]Idaho National Laboratory, Idaho Falls, ID*


Advanced nuclear reactor designs promise increased performance and safety over their predecessors. This promise, however, rests heavily on the behaviour of the materials used to construct the core of the reactors. These materials help contain the nuclear fuel and fission products while ensuring the efficient production of energy from the nuclear fuel. The operating conditions of advanced reactor concepts will place significant demands on their materials, reaching material damage levels almost six times more severe than those for existing nuclear plants. Many factors affect the mechanical response of these materials to the harsh environments of reactor cores, including the heat treatment process of the materials before use in the core and their subsequent irradiation. The effects that heat treatments may have on the microstructural evolution of materials that undergo irradiation has not been widely investigated.

The HT9 steel alloy (Fe-12Cr-1Mo-0.5W-0.5Ni-0.25V-0.2C in weight percent) has been studied extensively as a candidate material for use in the cores of advanced nuclear reactor designs due to its promising mechanical properties. However, HT9 undergoes multiple microstructural changes induced by radiation, such as microchemical changes in the form of precipitation or dissolution of phases. This can affect the strength of HT9 and limit the lifetime of future reactors. Currently, there is an insufficient understanding of how the processing of HT9 affects HT9's microstructural evolution under neutron irradiation. Hence, a study was conducted investigating the heat-to-heat variability of the radiation response of HT9.

Three sets of HT9 samples, each set having a different heat processing history but the same irradiation history, were analysed. The samples were irradiated at the Advanced Test Reactor at 430°C to 8 displacements per atom (dpa). Dpa is the number of times an atom has been knocked off its lattice site and it represents the damage imparted to the material from irradiation. The samples were processed and then examined via transmission electron microscopy (TEM) at the Irradiated Materials Characterization Laboratory at Idaho National Laboratory. Compositions of the precipitates were determined using energy dispersive spectroscopy in the microscope. Unirradiated control samples from each heat process were also observed using TEM.

The size, density, and composition of precipitates were evaluated from the data obtained with TEM. Equiaxed and elongated precipitates composed primarily of chromium and carbon were found in the unirradiated samples with enrichment of molybdenum, vanadium, and manganese. Irradiated samples produced mostly elongated chromium carbides. Vanadium nitride precipitation was also found in the unirradiated and irradiated conditions. The chromium carbides were larger in size and had a greater density than the vanadium nitrides in both conditions. Precipitation of both kinds was often favoured along grain boundaries. The unirradiated and irradiated microstructures showed no significant differences in size, density, or composition of precipitates. The microstructures of the irradiated samples were also found to be similar. There was no observation of the formation of precipitates induced solely by neutron irradiation, which has been found in studies where HT9 attained higher damage levels. Further analysis should be conducted to determine if heat treatment effects the microstructural response of HT9 at higher damage levels.

# Holistic and Predictive Safety Monitoring Toward Safe Human-Robot Collaboration in Construction (EGSR_48)


## Daeho Kim, SangHyun Lee

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


Autonomous robots have drawn increased attention in the construction industry as an effective means of improving safety and productivity. However, it is still challenging to ensure the safe collaboration between human and robot co-workers on dynamic and unstructured construction workspaces. On construction sites, multiple entities dynamically collaborate with each other, and the situational context between them evolves continually. Construction robots must thus be able to visually understand the scene's contexts in detail, thereby safely collaborating with humans, as a human vision system does.

Toward safe human-robot collaboration in construction, this study aims to make vision methods that can support construction robots to understand a visual scene in a holistic and predictive way. This study leverages drone, computer vision, and deep learning, specifically focusing on achieving three major tasks: (i) understanding of individual entities (i.e., location, proximity to others); (ii) understanding of the semantic relation between multiple entities; and (iii) understanding of feature scene contexts.

The first task starts with understanding the attributes of individual entities—such as one's identity, location, and pose. This information is useful not only for understanding spatial relationship between entities (i.e., proximity to each other), but also for detecting unsafe events—such as struck-by, caught-in, and caught-between hazards.  To this end, this study leverages a deep neural network (YOLO-V3) for object detection and develops a method that allows for the measurement of actual distance from a 2D image. Tests on real-site aerial videos showed the promising accuracy of the proposed method: the mean absolute percentage errors were around 4%.

Meanwhile, the second task seeks to understand the situational contexts of a scene—such as a semantic relation between a pair of entities. The holistic scene understanding is important for construction robots to take a better/safer action in unstructured construction sites. To achieve it, this study builds a unique deep network architecture (Px2Graph) that can detect semantic relations between construction entities. Test on real-site videos showed the promising accuracy of the proposed network: the network showed high generalization capability without any overfitting; the recall@100 on training and test dataset reached 91% and 88%, respectively.

As the last step, this study investigates the feasibility of future frame prediction for construction site videos. Many vision tasks (e.g., object detection, pose estimation, and relation detection) can be equipped with predictive power without further modification, once solid future frames are given as input sources. The predictive scene understanding can support the advanced detection of unsafe events, which can lead to the prevention of a potential accident with effective intervention. Toward this end, this study leverages a deep neural network (i.e., PredNet) and customizes it to construction settings. The fine-tuned model for construction showed a mean squared error of 0.002504, which is 41.46% higher than the MSE for the original model.

To summarize, this study aims to make safety monitoring in construction sites holistic and predictive, thereby supporting the safe collaboration between human and robot co-workers. These efforts will lay the technical foundation that can support the deployment of autonomous robots in construction, and will contribute to promoting safer working environment in construction sites.

# Low-Loss Power IC for PV Cell-Level Balancing Using Diffusion Charge Redistribution (EGSR_49)


## Yingying Fan[1], Yanqiao Li[1,2], Al-Thaddeus Avestruz[1]

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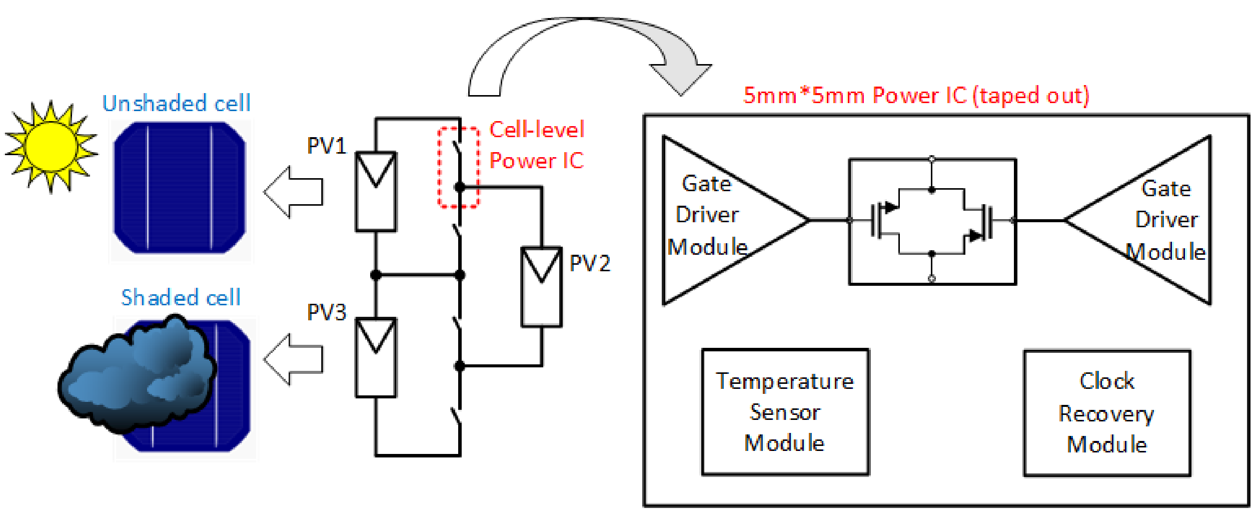
[2]*Department of Engineering, Dartmouth College, Hanover, NH*


Shading is a big problem for traditional solar systems. The power extracted from solar panels will drop severely even partial shading happens. The output current of panels is mainly constrained by that of shaded or 'weaker' cells because of the series string structure. Diffusion Charge Redistribution (DCR) takes advantage of the intrinsic capacitors in PV cells to achieve a balance between different cells. Power efficiency of panels with ladder structure using DCR strategy is much improved compared to panels with series string structure cells.

The Low-loss power IC we investigated is applied to be connected between PV cells in solar panels to redistribute the intrinsic stored charge in cells. This minimizes the effect of 'weaker' cells and extract maximum power from the panels. The power IC contains several modules. The core modules are large switches and complementary gate drivers. These switches are capable to conduct up to 10 Amp current and provide built-in ESD protection. Gate drivers are designed to drive the switches for balancing the delay and eliminating power loss. The switches with gate drivers have been optimized to have ultra-low on resistance 5 mΩ and fast switching speed. Additional modules such as temperature sensors and clock recovery modules are on-chip to help customers and researchers to easily monitor the working condition of this IC and the whole solar panel.

This Power IC is able to be integrated into solar panels to obtain additional output power when shading happens. In addition, this cell-level IC has high compatibility in commercial use.

The principle and diagram of our IC is shown as following.



# Morpheus: Securing Systems with Hardware-based Ensembles of Moving Target Defenses (EGSR_50)

**Mark Gallagher[1], Lauren Biernacki[1], Shibo Chen[1], Misiker Tadesse Aga[1], Zelalem Birhanu Aweke[1], Salessawi Ferede Yitbarek[1], Austin Harris[2], Zhixing Xu[3], Baris Kasikci[1], Valeria Bertacco[1], Sharad Malik[3], Mohit Tiwari[2], Todd Austin[1]**

*[1]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*
*[2]Department of Electrical and Computer Engineering, University of Texas at Austin, Austin, TX*
*[3]Department of Electrical Engineering, Princeton University, Princeton, NJ*

Secure system design has traditionally taken on a *reactive* defense approach, where patches are issued as vulnerabilities are discovered and exploited. This is extremely difficult to sustain, as programs grow in complexity and introduce more vulnerabilities. Rather than relying on finding all possible vulnerabilities, we propose a *proactive* defense approach, where we assume that vulnerabilities will always exist. Many of the attacks today use these vulnerabilities to leak key *information assets*, or pieces of data leveraged by an attacker in their exploits.

In the presence of vulnerabilities, we achieve vulnerability-tolerance through a design approach we call *ensembles of moving target defenses (EMTDs)*. In the EMTD methodology, we start with a key-driven randomization-based defense. An example of this is encryption, where a randomly-generated key is combined with a cipher to obfuscate information assets. We turn this defense into a *moving target* with a mechanism called *churn*, which allows for re-randomization of the defense at runtime. Finally, we layer multiple defenses to create an ensemble. Our goal in this system is to accept that information will be acquired by an attacker, and that they will attempt to use that information to exploit the system. However, churn will expire any information an attacker obtains, breaking their exploit attempts.

We apply the EMTD methodology to design the *Morpheus Architecture*, a secure computer architecture designed to be vulnerability-tolerant against control-flow exploits by protecting the very information assets attackers seek to gain. Our analysis of control-flow attacks found these vital assets to include the locations of code and data, the contents of code, and pointer values. In Morpheus, we introduce two moving target defenses to protect these information assets. The first is *address space displacement*, where we add unique displacements to all code and data pointers in a program, effectively shifting the address space. Secondly, we use *multi-domain encryption* to obfuscate code pointers, data pointers, and code under their own keys. We implement churn in hardware so that these two defenses can be efficiently rekeyed at runtime.

We evaluate Morpheus in a RISC-V-based prototype, showing that it provides additional security with low performance overhead. Using the gem5 cycle-accurate architecture simulator, we find that Morpheus defenses incur less than 1% slowdown on the SPEC’06 benchmark suite when defenses are rekeyed every 50 ms. This is significantly better than previous software-based re-randomization techniques. Morpheus is also shown to be effective at stopping a broad array of control-flow attacks, such as code injection and code reuse attacks, as attackers struggle to gather the information necessary to exploit the system.

Morpheus and the EMTD methodology can be extended to provide additional coverage against a multitude of attack classes and information assets. We envision future work will provide value in churning more defenses and assets at a low performance cost.

# Learning through Robot-Object Interactions (EGSR_51)

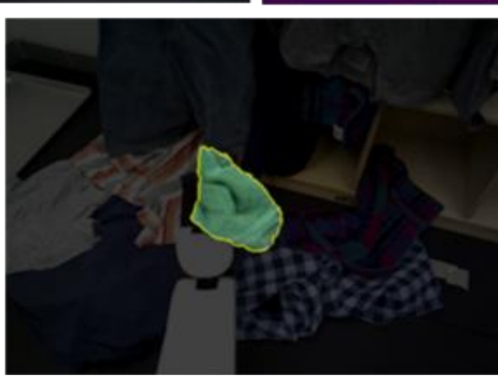
## Victoria Florence[1], Brent Griffin[1,2], Sajan Patel[1], Jason J Corso[1,2]

[1] *The Robotics Institute, University of Michigan, Ann Arbor, MI*

[2] *Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*

Currently, many robots are used in industrial applications in order to increase precision, productivity, and safety for humans. Additionally, there are many opportunities to extend the benefits of robotics past this set of tasks to less controlled domains where humans live their everyday lives; however, robots outside of the highly structured factory environment have to plan around the actions and movements of external agents. Since all of the moving pieces in the world would be unpractical to track, many previous works have used cameras with various image processing methods to recognize and localize objects in the environment as the robot encounters them. One bottleneck on these systems is that most require some sort of human-in-the-loop semantic description or labeling of previously saved images or video. Using this data as training data, the robot learns to describe or label new images of objects in the training data in order to perform new tasks.

In order to combat this bottleneck, we present an algorithmic pipeline that aims to perform the job of a human annotator with decreased work on the part of the human. Using the known locations of the robot gripper along with sequential depth and RGB image segmentations (see figure below), we locate pixels in the depth and RGB images which correspond to the object being gripped by the robot. In this way, we produce training data that is specific to the new object and ignores background clutter without having a human label the desired object after the fact. This method will allow robot vision systems to acquire new training data, and consequently, learn new objects in the environment, more quickly.



RGB(top left) and depth(top right) images labeled with known points on the robot gripper in blue and yellow respectively. The output of our pipeline is shown on the bottom row.

# Experimental Study on the Effects of Thermal Barrier Coatings on Heavy Duty Diesel Engine Efficiency and NOx Emissions (EGSR_52)


## Erick Garcia, Andre L. Boehman

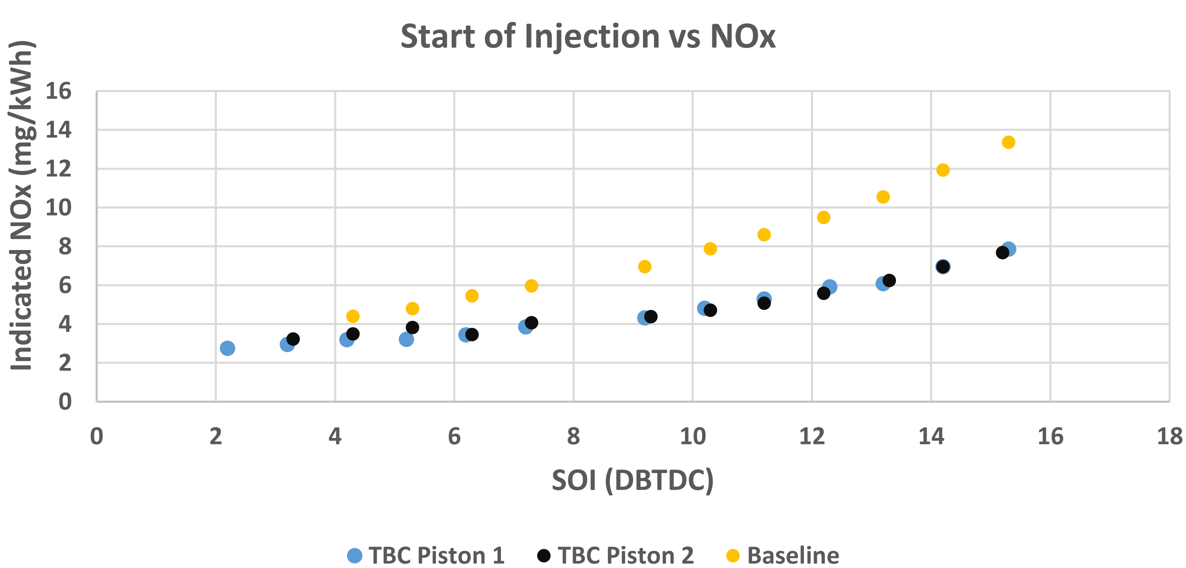
*Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI*


Today's diesel engines only convert about 30-40% of the fuel energy consumed into work. The rest of the fuel energy is split approximately evenly between the energy dissipated as a cooling loss and the energy sent out the exhaust. The use of thermal barrier coatings (TBCs) have been shown to reduce this cooling loss and promote increased conversion of fuel energy to work and heat in the exhaust.

This study analyzes the impact that applying a TBC onto a next generation heavy duty (HD) diesel engine piston design has on thermal efficiency and NOx emissions. The coating utilized in this study is a plasma sprayed ceria stabilized zirconia that covers the entire crown of the piston. The coating allows the piston crown's surface to reach higher temperatures than normal, reducing the gradient driving heat transfer between the combustion gases and the piston crown. The results of this study will help determine if this piston design will end up in an engine being developed by Volvo's SuperTruck II team. The goal is for that engine to obtain 55% brake thermal efficiency (BTE) while meeting today's stringent emission mandates.

Two TBC pistons of varying coating thicknesses were evaluated using a HD single cylinder research engine (SCRE). Both pistons showed NOx reductions (on a g/kWh basis) across all test conditions compared to a non-coated baseline piston, without significant increases in soot emissions that typically go hand-in-hand with reductions in NOx. However, they also showed an increase in indicated specific fuel consumption (ISFC) across all test conditions, with the thinner coating increasing ISFC the most.

These results prompted further investigation to understand the cause of the NOx-ISFC tradeoff found among both coatings. The effect of the coating's surface roughness will be investigated as literature suggests it is best to have a smooth, or less porous, surface. Both of the TBC pistons tested had rougher crown surfaces than the non-coated baseline piston. Smoothed versions of the TBC pistons have already been obtained and will be evaluated to determine if there is an ISFC benefit to be gained from the smoother TBC surface as well as a potential further reduction in the NOx-PM tradeoff observed in this study.



# Design for Optimized Composite Structures Including Manufacturing Induced Defects (EGSR_54)

Minh Hoang Nguyen, Avinkrishnan Vijayachandran, Paul Davidson, Anthony M. Waas
*Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI*

Automated manufacturing of large composite structures is on the rise across multiple industry sectors, from wind energy and infrastructure to aerospace and marine applications. The main intended benefit of automation is lower cost through scarp reduction (additive manufacturing) and improved production cycle when compared to traditional hand-layup. Another benefit of automation with Automated Fiber Placement (AFP) is the ability to tailor the layup based on geometry and loading conditions though fiber steering i.e.; fiber paths can now be placed based on designs that optimize specified metrics, such as stress concentrations or buckling loads. The process though, has inherent defects that arise and requires a detailed study on the effect of these defects so as to design optimal structures; and to develop accurate predictive models for failure. In this poster, we focus on detailed experimental studies on the effect of manufacturing induced defects on structural performance and computational models incorporating these defects while optimizing for critical load bearing structures with cutouts that are common in aerospace design.

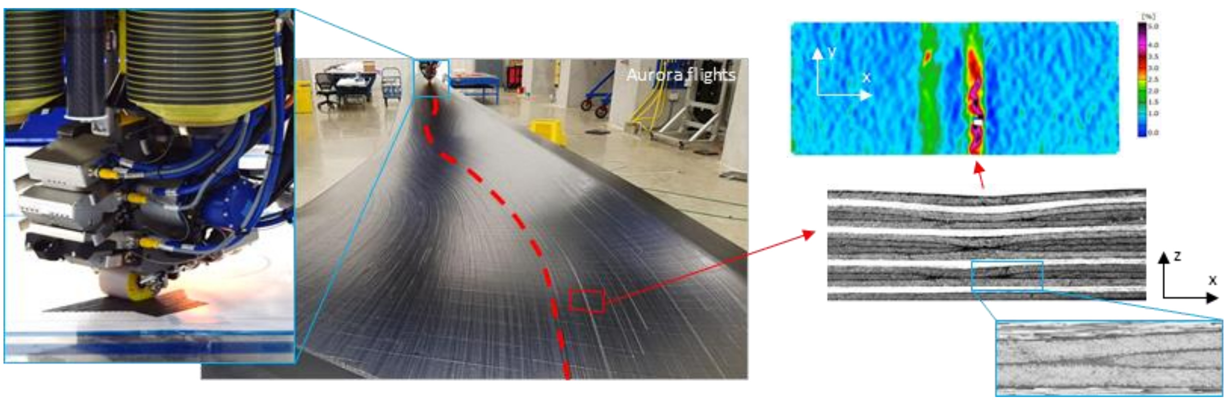



*Figure 1: AFP-manufactured aircraft wing using steered fibers with induced defects.*

Controlled carbon fiber composite panels with imperfections like gaps, overlaps and missing tows were manufactured using a production quality AFP machine. Panels without defects were also manufactured using traditional hand-layup, for baseline measurements. Microscopic and C Scan measurements were conducted for accurate characterization of imperfect microstructure produced due to curing and consolidation. Specimens were cut from the panels for examining the tensile and compressive strengths. The paper will report initial test results for variations in tensile and compressive stiffness and strength, due to the presence of manufacturing induced imperfections.

Optimization of structural performance of aerospace structures using steering of fiber paths has been conducted and reported in literature. However, most studies don’t account for the manufacturing aspect of fiber steering using AFP machines. Numerical models for steered fiber composites are generated through automated python based scripts. Manufacturing constraints are included in the analysis through explicitly modeling the gaps, overlaps and curvatures of each tool pass.

# Estimating the Aurora's electrical Conductance – Improvements in Space Weather Forecasting (EGSR_55)

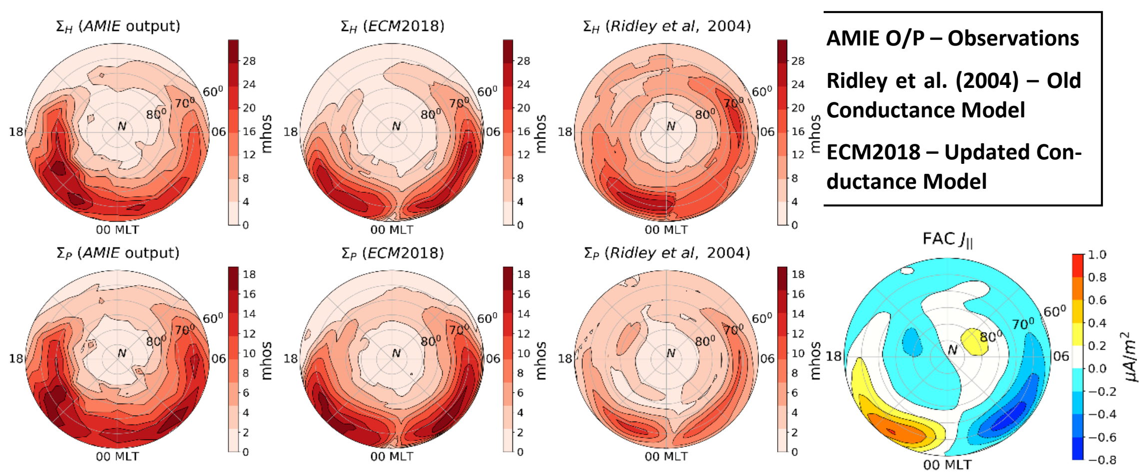
**Agnit Mukhopadhyay[1], Daniel T Welling[1,2], Michael W Liemohn[1], Shasha Zou[1], Aaron Ridley[1], Meghan Burleigh[1]**

[1]*Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI*

[2]*Department of Physics, The University of Texas at Arlington, Arlington, TX*

The interaction of the Earth's intrinsic magnetic field with the solar wind plasma produces a myriad of magnetospheric current systems, some of which like the field aligned currents close through the ionosphere and the upper atmosphere. The closing of these currents and their effect on the ground is heavily influenced by the height-integrated electrical conductivity or conductance of the ionosphere. Since the prediction of these current systems during space weather activity greatly affects the prediction of geomagnetically induced currents, which have detrimental effects on electrical power grids and oil pipelines, the accurate estimation of the ionospheric conductance, especially in the auroral region, is a necessity for modern space weather predictive models. In the following study, we present initial validation results from the updated empirical conductance model in the University of Michigan's Space Weather Modeling Framework (SWMF, *Toth et al. 2005, 2012*) and describe the initial computational layout towards estimating the ionospheric conductance using a first principles-based method.

In updating the existing empirical conductance model, we used one year's worth minute-resolution auroral conductance data derived from the assimilative mapping method of ionospheric electrodynamics (*Ridley et al. 2004*) to draw an inverse exponential relationship between the field aligned currents and the ionospheric conductance for any given location. Using the updated conductance model, we show new validation results following the same analysis techniques used in the GEM Challenge of 2008 (*Pulkkinen et al. 2013*). We find that space weather predictions of ground magnetic perturbation significantly, especially during stronger driving of the solar wind.




**Comparisons between the updated and older conductance model run in the SWMF for the same event (Halloween Storm of 2003) and compared against AMIE observations.**

# High-Throughput Microfluidic Platforms to Deconstruct and Engineer Cellular Fusion (EGSR_56)

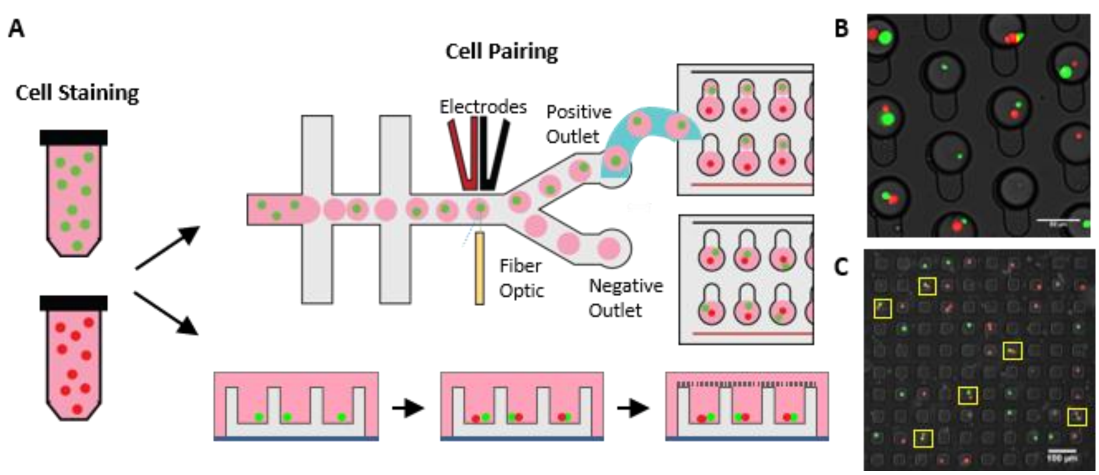

**Benjamin Yang[1], Meng-Ting Chung[2], Katsuo Kurabayashi[2], Carlos Aguilar[1]**

*[1]Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI*

*[2]Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI*



Cellular fusion, the process by which cells combine and share cytoplasmic material, is a process of central importance to a broad spectrum of essential functions in development, homeostasis, and disease. Cell-cell fusion events initiate development through fertilization; regulate the formation of muscle, bone, and the placenta; and facilitate vital processes in our mature lives such as musculoskeletal repair and the immune response. Furthermore, disruptions of fusogenic events are linked to the pathogenesis of a range of diseases, including osteoporosis, skeletal muscle malformations, and tumorigenesis. However, while many proteins associated with cellular fusion have been identified, the underlying molecular mechanisms that drive fusogenic processes are largely unknown. Current methods for studying cellular fusion in vitro rely on co-culture techniques that lack precise control over the pairing process and are insensitive to the heterogeneity exhibited by individual cells. Here, we present droplet-based and gravity-driven co-confinement microfluidic platforms that can deterministically pair heterotypic cells in engineered microenvironments and analyze the transcriptome of each fusion event via single-cell mRNA-sequencing (scRNA-Seq). To establish the potential of these novel approaches for translational applications, we focus primarily on the well-characterized system formed from the fusion of mouse muscle stem cells (MuSCs) which has potential to improve cell-based therapies for muscular dystrophies. We demonstrate that C2C12 mouse myoblasts stained with two colors of fluorescent dye can be paired in microfluidic platforms for fusion, lysis, and mRNA transcript capture. The platforms developed in this work overcome the limitations of conventional fusion assays and have the potential to tease apart the transcriptional networks that regulate cellular fusion in a diverse range of cell types, enabling the development of novel therapies that manage a myriad of diseases and improve tissue repair.

# Investigations of the Electromagnetic Properties of Fluorinated Nano-$Fe_3O_4$ and its Carbon-Based Compound (EGSR_57)

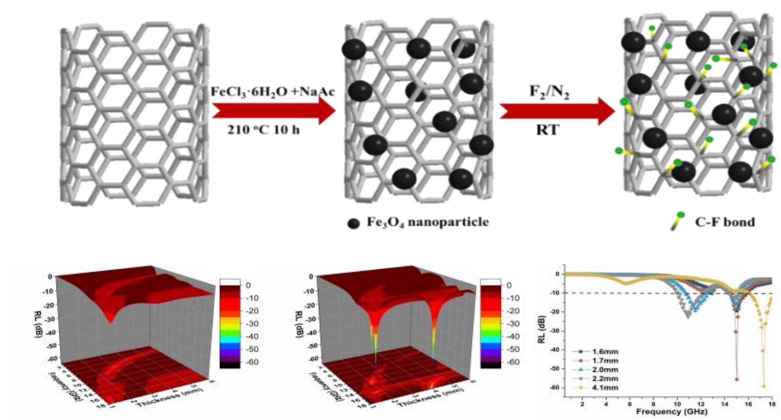

## Yichun Zhang[1], Xiangyang Liu[2]

*[1]Macromolecular Science and Engineering Program, University of Michigan, Ann Arbor, MI*

*[2]Department of Polymer Science and Engineering, Sichuan University, Chengdu, Sichuan, CN*



As one traditional microwave absorption material, ferrites are possessed with strong attenuation ability, but at the same time have some drawbacks including sole loss mechanism, high density, high filler content and large thickness, etc. In this work, direct fluorination was utilized to modify nano- $Fe_3O_4$. The lattice structure of as-prepared fluorinated $Fe_3O_4$ is strongly associated with the fluorine content. At low fluorine content, the fluorine atoms would dope into tetrahedral and octahedral site, while maintaining the overall crystal structure; with rising fluorine content, new crystal phases start to form, including $FeF_3 \cdot 3H_2O$ and FeOOH, while the crystal structures of $Fe_3O_4$ are damaged. for the electromagnetic parameters, at low fluorine content, the doped fluorine atoms would enhance dipole polarization and exchange resonance intensity, which lead to the increase of dielectric constant as well as resonance peak in permittivity at frequency higher than 14GHz and finally excellent microwave absorption properties: the minimum reflection loss is -60.46dB at the thickness of 6.5mm, and the effective absorption width is 4.9GHz. However, the drawbacks of ferrites absorber including high density, high filler content and large thickness still need to be addressed. To further improve the absorption properties, $Fe_3O_4$ was coated on carbon nanotubes (CNTs) and then fluorinated at room temperature. The result shows that $Fe_3O_4$ could catalyze fluorination of CNTs, and $-CF_2$, $-CF_3$ are the major fluorine-containing groups. The reason is that complexation of $Fe^{3+}$ could induce negative charge accumulation at the defects, which promote the attack of fluorine gas of carbon atoms at the defects. Therefore, by loading $Fe_3O_4$, CNTs with high fluorine content could be prepared at low temperature. The fluorination enhances exchange resonance intensity of $Fe_3O_4$, while improve the impedance matching of CNTs, which endows $Fe_3O_4$@CNTs with good microwave absorption properties at smaller thickness: at the thickness of 4.1mm, the minimum reflection loss is -59.6dB, and the effective absorption region covers from 16-18GHz. Our results demonstrate the promising application prospects of direct fluorination technique in modification of ferrites and their carbon-based compounds.


**Preparation method and microwave absorbing properties of $Fe_3O_4$@CNTs.**

# Three-Dimensional Graphene Oxide Skeleton Guided Polyacrylic Acid Composite Hydrogel Particles with Hierarchical Pore Structure for Hemoperfusion (EGSR_58)

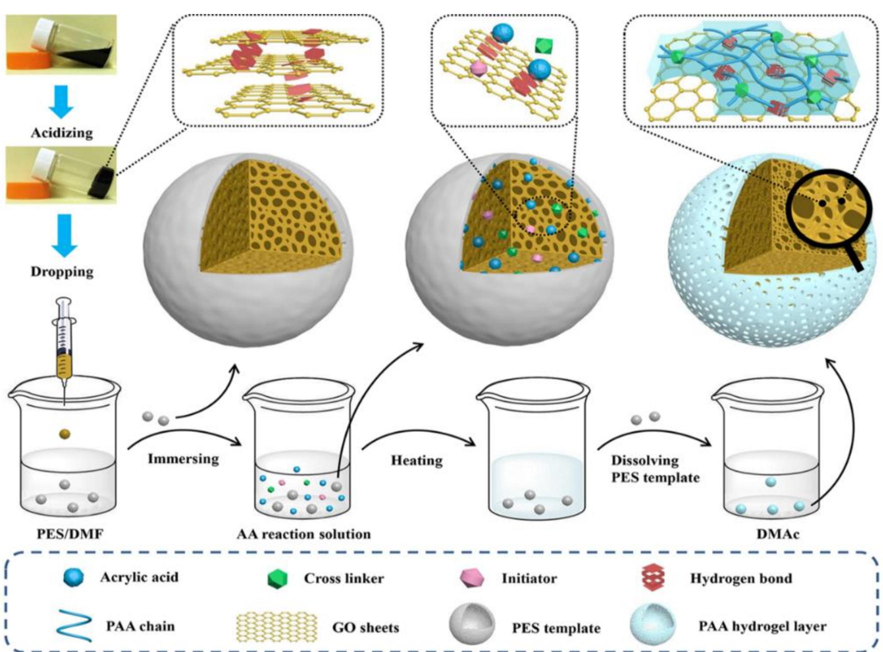

## Jukai Zhou[1], Shuqing Zhang[1], Xiang Zhang[2], Changsheng Zhao[2]

[1]*Macromolecular Science and Engineering Program, University of Michigan, Ann Arbor, MI*

[2]*Department of Polymer Science and Engineering, Sichuan University, Chengdu, Sichuan, CN*



In this study, three-dimensional (3D) graphene oxide (GO) skeleton guided polyacrylic acid (PAA) composite hydrogel particles (HPs) were prepared by a core-shell template method. The 3D GO skeletons with millimeter-scale were firstly constructed with the assistance of templates, dissolvable polyethersulfone hollow particles, which were prepared by a phase inversion technique; then PAA hydrogels were formed on the surface of the 3D GO skeleton. The obtained HPs showed a spherical shape, uniform size and special hierarchical pore microstructure. Compared with pure PAA hydrogels, the swelling ratios of the HPs were significantly restricted, and the porosities were remarkably increased; the compressive stress and the elongation at break were improved at the same time. The hemocompatibility tests, including protein adsorption, hemolysis ratio, complement and contact activation, platelet adhesion and clotting time were carried out, and the results indicated that the HPs showed good hemocompatibility. The adsorption results indicated that the HPs exhibited good removal efficiency toward exogenous and endogenous toxins. In general, the suitable physical and mechanical properties, the excellent hemocompatibility and adsorption capacities made the composite hydrogel particle a promising candidate for the novel hemoperfusion adsorbent.

# Richard and Eleanor Towner Prize for Outstanding Ph.D. Research Oral and Poster Competition (TOWNER)

# Afternoon Session:
# 2:00 pm – 4:00 pm
# Duderstadt Gallery

# Afternoon Towner Session Nominees

| Department | Name | Advisor |
|---|---|---|
| AERO | Danning Huang | Peretz Friedmann |
| BME | James Day | Ariella Shikanov |
| ChE | Douglas Montjoy | Nick Kotov |
| CEE | Jubilee Adeoye | Brian Ellis |
| CSE | John Gideon | Emily Mower Provost |
| ECE | Mohammadmahdi Khaliligarakani | Mingyan Liu |
| IOE | Yiling Zhang | Siqian Shen |
| MACRO | Harry Van der Laan | Timothy Scott |
| MSE | Regina Garcia | Jeff Sakamoto |
| ME | Amin Ghadami | Bogdan I. Epureanu |
| NERS | Stephen Taller | Gary Was |
| Robotics | Mia Stevens | Ella Atkins |

# Afternoon Towner Abstracts

## Towards Hypersonic Aerothermoelastic Scaling Laws (TOWNER_2)


### Daning Huang, Peretz P. Friedmann

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



Airbreathing hypersonic vehicles have transformative potential to revolutionize the global transportation: They are expected to operate in the atmosphere at a speed over five times faster than the speed of sound, thus enabling rapid transportation between distant locations, and reducing flight time to a couple of hours. Unlike conventional commercial aircraft, airbreathing hypersonic vehicles are inherently multidisciplinary: the aerodynamic, structural and thermal responses are tightly coupled, and interact with the propulsion system. Due to the high speeds, the vehicle is exposed to extreme aerothermodynamic environment involving high aerodynamic loading and heating. The adverse working environment leads to the accumulation of thermal stresses and the degradation of material properties, deteriorating structural integrity and causing structural instabilities, including buckling (i.e. loss of load-carrying capability) and flutter (i.e. self- excited oscillation due to fluid-structure interaction). Therefore, successful design of airbreathing hypersonic vehicles requires a combined multi-physics model where several disciplines such as aerodynamics, structural dynamics and heat transfer are strongly coupled producing a fluid- structural-thermal interaction problem usually denoted by the term aerothermoelasticity.

One of the major challenges associated with the design of hypersonic vehicles is the lack of scaling laws for hypersonic aerothermoelastic testing that precludes experimental validation of the vehicle design. Aerothermoelastic testing refers to the construction of a scaled version of the prototype vehicle and its direct insertion into a high-stagnation-temperature wind tunnel where the scaled model can be exposed to aerodynamic heating and loading simultaneously. This approach is impractical due to the lack of aerothermoelastic scaling laws required for the construction of scaled models and mapping of the experimental results back to the full-scale prototype. Therefore, it is not surprising that design of airbreathing hypersonic vehicles has encountered numerous difficulties in the past, including failures during flight as well as high temperature structural testing. Nevertheless, the work conducted on hypersonic vehicles in the 1960s developed a theoretical framework for obtaining aerothermoelastic scaling laws and concluded that complete similarity is impossible to achieve for scale ratios that differ from unity.

In the current study, a new, two-pronged approach is proposed for obtaining aerothermoelastic scaling laws, which combines the classical theoretical approach with modern numerical approach based on computational aerothermoelasticity. On one hand, basic scaling requirements are established using theoretical analysis, in a manner that resembles the classical procedure developed in 1960's. On the other hand, numerical simulations are used to generate "numerical similarity solutions" that can replace the analytical similarity solutions for refinement of the scaling laws, which overcome the difficulties encountered in the analytical work. The procedure for scaling law refinement is formulated in the generalized form of a constrained optimization problem, which is applicable to several components of an airbreathing hypersonic vehicle. Eventually, using the methodology developed in this study, some of the flight tests on a full-size vehicle could be replaced by wind tunnel experiments on the scaled models, which could reduce the cost of hypersonic vehicle development by one or two orders of magnitude. Therefore, it has the potential for saving large amounts of funding required for developing hypersonic vehicles and thus accelerate the advent of a new era of airbreathing hypersonic flight.

# Immunoisolating Poly(Ethylene Glycol) Capsules Support Ovarian Tissue Survival and Development to Restore Reproductive Endocrine Function in Mice (TOWNER_3)

**James R. Day[1], Anu David[1], Marilia Cascalho[3], Ariella Shikanov[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*

[3]*Department of Surgery, University of Michigan, Ann Arbor, MI*

Fortunately, the number of young female cancer survivors has increased over the past decade due to advances in diagnosis and highly efficacious radio- and chemo-therapeutic treatments. These survivors, however, may face long-term health issues related to treatment toxicity. One of these issues, impacting a large subset of young women cancer survivors, is the elimination of the follicular pool in the ovary leading to estrogen deficiency. The importance of functional ovaries extends throughout the endocrine system, as proper ovarian endocrine function is instrumental in maintaining physiological feedback with other tissues. An option for patients experiencing endocrine deficiency resulting from premature ovarian insufficiency is the cryopreservation of ovarian tissue and auto-transplantation after treatments are complete. Unfortunately, auto-transplantation presents the risk of re-introducing malignant cells harbored in the stroma of the implanted tissue and is contra indicated in hematological cancer survivors. To avoid this risk, an ovarian tissue allograft from a healthy donor implanted in an immunoisolating capsule can restore the loss of ovarian endocrine function. We designed a hydrogel based dual capsule that supports the survival and function of the ovarian allograft without systemic immunosuppression.

We designed a dual immunoisolating capsule (PEG-Dual) by tuning the physical properties of the PEG hydrogels and combining proteolytically degradable (PEG-PD) and non- degradable (PEG-NPD) layers to meet the numerous requirements for encapsulation and immunoisolation of ovarian tissue, such as nutrient diffusion and tissue expansion. Tuning the components of the PEG-Dual capsule to have similar physical properties allowed for concentric encapsulation. Mice were ovariectomized in a premature ovarian failure mouse model to induce menopause. The three constructs of interest were then subcutaneously implanted for 7, 30, and 60 days.

Ovarian tissue encapsulated in the our three constructs functioned for 60 days post implantation and restored regular estrous cyclicity and ovarian endocrine function in ovariectomized mice. The serum levels of follicular stimulating hormone (FSH) in mice decreased significantly after implantation compared to pre-implantation levels (Figure 1) and confirms the negative feedback of estradiol secreted from the ovarian tissue. Healthy follicles at different developmental stages appeared in histological analysis of the retrieved implants, which further supports healthy folliculogenesis and sex steroid production.

This study demonstrated for the first time that immunoisolating PEG-VS capsules can support ovarian follicular development resulting in the restoration of ovarian endocrine function and can be applied to future allogeneic studies.

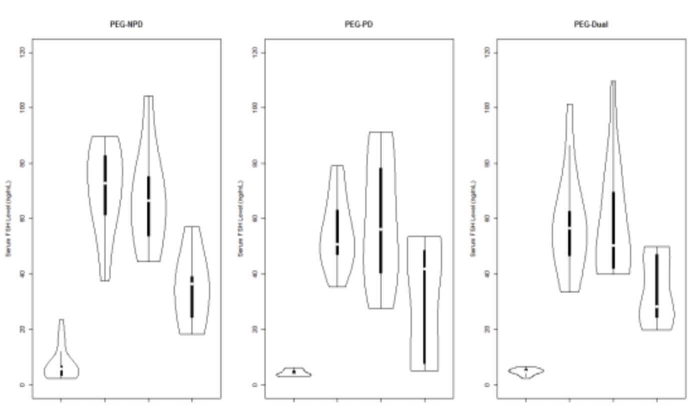



Figure 1: FSH levels of mice receiving ovarian tissue encapsulated in PEG-NPD, PEG-PD, and PEG-Dual up to 60 days.

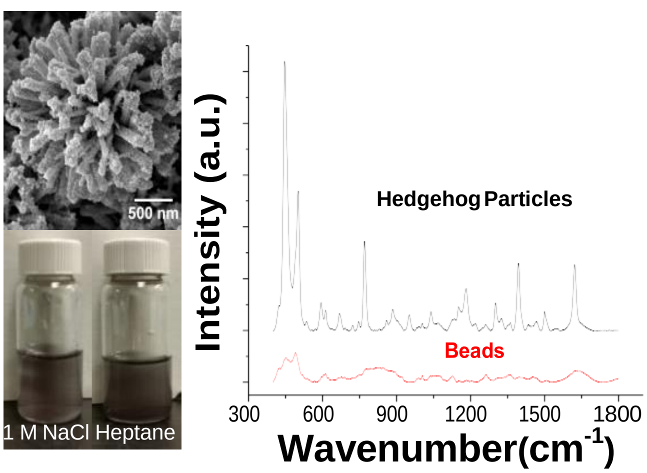
## Hedgehog Particles (TOWNER_6)


**Douglas G. Montjoy[1], Joong Hwan Bahng[2], Harrison Hou[1], Aydin Eskafi[1], Nicholas Kotov[1,2,3,4]**

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



Particle stability is critical for development of new catalysts to produce sustainable fuels as well as sensors to detect bacteria and other pathogens. Hedgehog particles (HPs) with stiff nanoscale spikes drastically reduce attractive van der Waals interactions compared to particles of the same dimensions with smooth surfaces enabling dispersion in both polar and nonpolar environments. Here we show that HPs carrying dense conformal coatings made by layer-by- layer (LBL) assembly maintain dispersion stability in environments of extreme polarity and ionic strength. In addition, we expand HPs to new inert and active inorganic core materials including silica and hematite by utilizing LBL polyelectrolyte films. HPs surface-modified by multilayers of polymers and nanoparticles overcome the limited colloidal stability of other SERS probes resulting in greater than one order of magnitude increase of SERS intensity compared to colloids with smooth surfaces and allow for simultaneous detection of several targets in complex media with high ionic strength. Inorganic HPs after liquid-state deposition of titanium dioxide demonstrate superior photocatalytic activity in a probe reaction in chloroform indicating promise for use in nonpolar media. HPs can directly affect the oxidation of cyclohexane to produce nylon and sustainable fuel production from carbon dioxide, both hindered by poor catalyst dispersion in nonpolar environments. HPs enable fine-tuned control of intermolecular forces enabling stability in a wide array of chemical environments and leading to applications in biomedicine and sustainable energy.

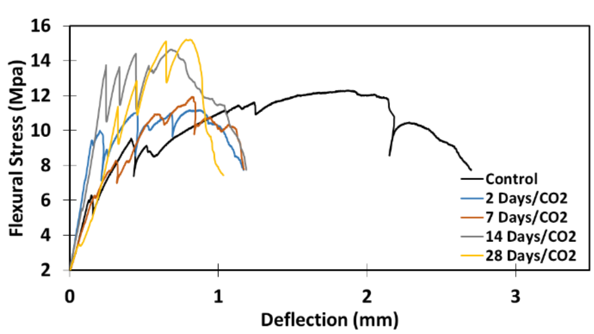



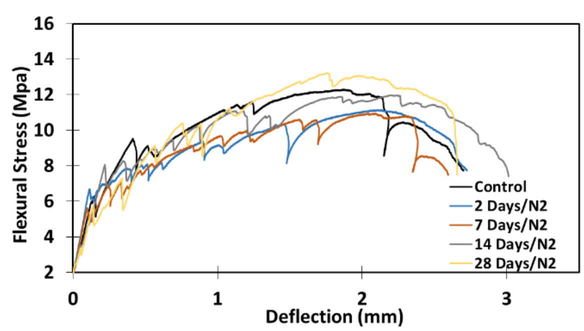
# Mechanical Integrity of Engineered Cementitious Composite during Geologic Carbon Storage (TOWNER_8)

**Jubilee Adeoye, Victor Li, Brian Ellis**
*Department Civil and Environmental Engineering, University of Michigan, Ann Arbor, Michigan*

Preventing leakage of $CO_2$ along wellbore cement sheaths is a key factor for ensuring success of geologic carbon storage (GCS) operations. Here, we examine a potential alternative cementing material, engineered cementitious composites (ECC), for use in GCS wellbore cementing applications. ECC is a novel fiber-reinforced cementitious composite that exhibits strain hardening and improved tensile ductility in comparison to conventional cement. Improved ductility may prevent wellbore damage caused by $CO_2$ injection pressures and casing expansion/contraction associated with thermal swings. Earlier work examining physical alterations of ECC exposed to $CO_2$ at 10 MPa and 50°C found that damage to ECC was limited to microcracks with apertures less than 60 µm after several weeks of reaction. However, microstructural analysis revealed densification of the fiber/matrix interphase due to calcite precipitation, which could alter the engineered bonding properties between the matrix and fibers. Such alteration following carbonation could negatively impact the long-term ductility of ECC used for GCS wellbore cementing applications.

This presentation will discuss recent results from static batch studies investigating the impact of CO2-acidified water on tensile ductility of ECC. Several ECC and ordinary Portland cement (OPC) coupons were exposed to CO2-saturated water under temperature and pressure conditions of 50oC and 10 MPa, respectively, and samples were retrieved after 2, 7, 14, and 28 days. Four-point flexural test and micro-CT analysis were carried out to investigate the impact of carbonation on the ductility and microstructural properties of ECC. Replicate experiments were also conducted under the same conditions but with a N2 headspace to isolate impacts associated with CO2 exposure. While the samples exposed to N2 continued to exhibit a multiple microcracking behavior with no observable change in tensile ductility, the ductility of the composite exposed to CO2-acidified water showed an increase in the ultimate flexural strength and significant decrease in ductility inferred from the extent of deflection as the duration of reaction increased (see figure below). OPC coupons exhibited brittle behaviors under all test conditions. This suggests that the densification of the fiber matrix interface after exposure to CO2 can compromise ECC's overall ductility.



# Improving Cross-Corpus Speech Emotion Recognition with Adversarial Discriminative Domain Generalization (ADDoG) (TOWNER_12)


## John Gideon[1], Melvin McInnis[2], Emily Mower Provost[1]

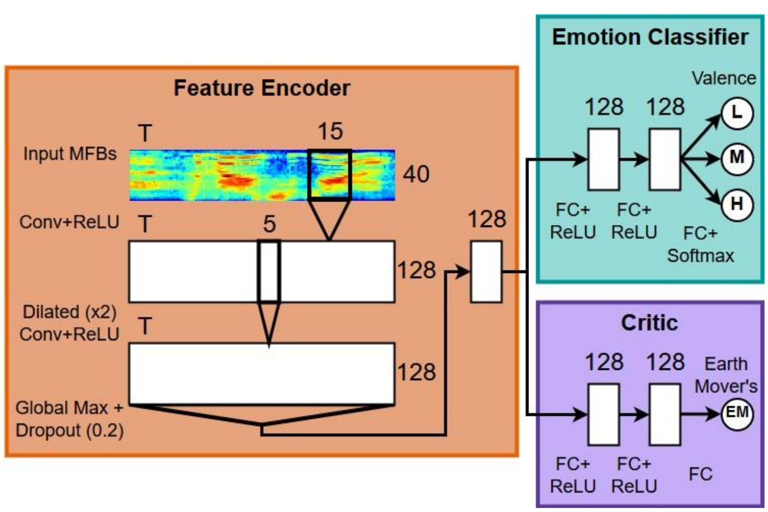
[1] *Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI*

[2] *Department of Psychiatry, University of Michigan, Ann Arbor, MI*


Automatic speech emotion recognition provides computers with critical context to enable user understanding. However, deployment of emotion recognition technologies in real world practice is challenging. While emotion recognition methods trained and tested within the same dataset have been shown successful, they often fail when applied to an unseen dataset. To address this, recent work has focused on adversarial methods to identify more generalized representations of emotional speech. However, many of these methods ultimately fail to converge. Furthermore, the analysis of these methods has only focused on datasets collected in laboratory conditions.

In this work, we address these limitations by introducing Adversarial Discriminative Domain Generalization (ADDoG), which solves these problems by following an easier to train "meet in the middle" approach. The model iteratively moves representations learned for each dataset closer to one another, improving cross-dataset generalization. We also introduce a multiclass extension, Multiclass ADDoG, or MADDoG, which extends the proposed method to more than two datasets, simultaneously. We demonstrate the efficacy of the approach both with and without small amounts of labelled target data and also explore the impact of mixing laboratory and in-the-wild recordings.

Our results show consistent convergence for the ADDoG and MADDoG methods in all experiments, with significantly improved results when not using labels from the target dataset. We also show how, in most cases, ADDoG and MADDoG significantly improve upon baseline state-of-the-art methods when target dataset labels are added and in-the-wild data are considered. Even though our experiments focus on cross-corpus speech emotion, these methods could be used to remove unwanted factors of variation in other settings. Furthermore, we plan to continue investigating emotion variability for the monitoring of mood in individuals with Bipolar Disorder using recordings of everyday phone conversations. The generalized emotion representations introduced in this work will provide a better framework for mobile health applications, such as this.



# Designing Cyber Insurance Policies: The Role of Pre-Screening and Security Interdependence (TOWNER_14)


## Mohammad Mahdi Khalili[1], Parinaz Naghizadeh[2], Mingyan Liu[1]

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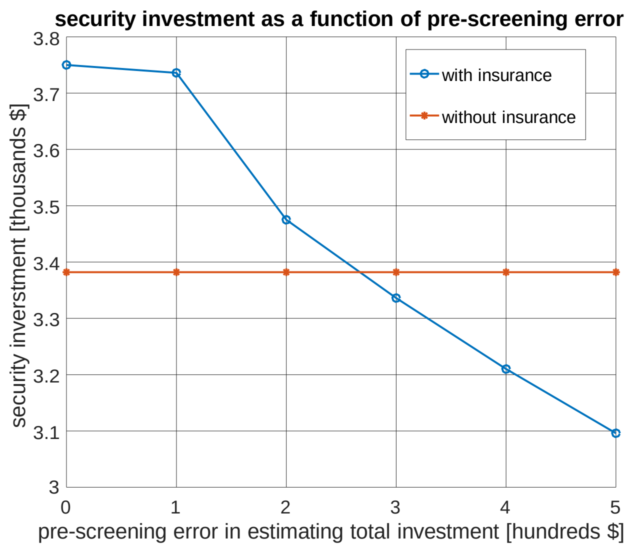
Cyber insurance is a viable method for cyber risk transfer. However, it has been shown that in the presence of a profit-maximizing insurer, the cyber insurance does not improve the state of network security as compared to the no-insurance scenario. In this work, we consider a single profit-maximizing insurer with voluntarily participating insureds. We are particularly interested in two distinct features of cybersecurity and their impact on the contract design problem. The first is the interdependent nature of cybersecurity, whereby one entity's state of security depends not only on its own investment and effort, but also the efforts of others' in the same eco-system (i.e., externalities). The second is the fact that recent advances in Internet measurement combined with machine learning techniques now allow us to perform accurate quantitative assessments of security posture at a firm level. This can be used as a tool to perform an initial security audit, or pre-screening, of a prospective client to better enable premium discrimination and the design of customized policies. We show that security interdependency leads to a “profit opportunity” for the insurer, created by the inefficient effort levels exerted by interdependent agents who do not account for the risk externalities when insurance is not available; this is in addition to risk transfer that an insurer typically profits from. Security pre-screening then allows the insurer to take advantage of this additional profit opportunity by designing the appropriate contracts which incentivize agents to increase their effort levels, allowing the insurer to “sell commitment” to interdependent agents, in addition to insuring their risks. We identify conditions under which this type of contract leads to not only increased profit for the principal, but also an improved state of network security. The following figure shows an example and implies if the pre-screening is accurate enough, the firms invest more in security after purchasing an insurance product.

# Distributionally Robust Building Load Control to Compensate Fluctuations in Solar Power Generation (TOWNER_16)

**Yiling Zhang[1], Jin Dong[2], Teja Kuruganti[2], Siqian Shen[1] and Yaosuo Xue[2]**

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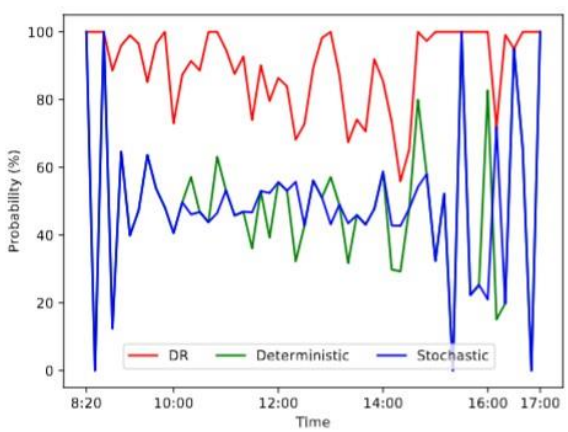
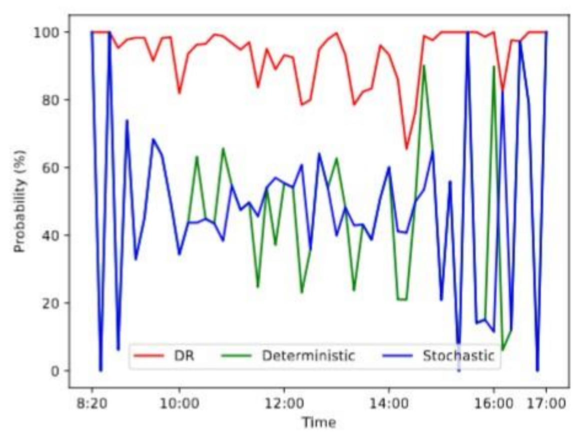
This paper investigates the use of a collection of dispatchable heating, ventilation and air conditioning (HVAC) systems to absorb low-frequency fluctuations in renewable energy sources, especially in solar photo-voltaic (PV) generation. Given the uncertain and time-varying nature of solar PV generation, its probability distribution is difficult to be estimated perfectly, which poses a challenging problem of how to optimally schedule a fleet of HVAC loads to consume as much as local PV generation. We formulate a distributionally robust chance-constrained (DRCC) model to ensure that PV generation is consumed with a desirable probability for a family of probability distributions, termed as an ambiguity set, built upon mean and covariance information. We benchmark the DRCC model with a deterministic optimization model and a stochastic programming model in a one-day simulation. We show that the DRCC model achieves constantly good performance to consume most PV generation even in the case with the presence of probability distribution ambiguity.

Key Results:

Out-of-sample performance




Under Uniform noises




Under Gaussian noises

1) Multi-period stochastic programming models experience computational difficulty.
2) DRCC approaches achieve constantly good performance to track most of PV generation even with the presence of distribution ambiguity.

# Hexaarylbiimidazoles as Efficient Photoinhibitors of Radical-Mediated Chain Growth Photopolymerizations (TOWNER_18)


## Harry L. van der Laan, Megan A. Cole[2], Timothy F. Scott[1,2]

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Owing to the inherent reactivity of organic radicals, the identification of photo-cleavable radical polymerization terminators that do not initiate polymerization has proven challenging. Moreover, to obtain wavelength-selective photoinitiation and photoinhibition in a formulated resin, initiating species need to be generated by irradiation at one wavelength while inhibiting species are generated at a second, independent wavelength, necessitating complementary photoinitiatior and photoinhibitor absorbance spectra. Hexaarylbiimidazoles (HABIs) to generate poorly reactive lophyl radicals upon UV light irradiation which recombine slowly and do not directly initiate the radical-mediated chain growth polymerization of (meth)acrylates; nevertheless, in the presence of hydrogen-donating species such as thiols, HABIs are well-known as photoinitiators of radical polymerizations. Here, we discuss the potential of HABIs as efficient radical polymerization photoinhibitors when used in conjunction with complementary photoinitiators, such as the camphorquinine/tertiary amine system. By monitoring the polymerization of formulated acrylate, methacrylate, and maleimide/vinyl ether resin formulations with Fourier transform infrared (FT-IR), UV-vis, and electron paramagnetic resonance (EPR) spectroscopic techniques, we establish the temporal and spatial control over the cure of these resins through wavelength-selective photoinitiation and photoinhibition *via* the photo-generation of polymerization-inhibiting lophyl radicals.

# Enabling Solid-State Batteries by Understanding Solid Electrolyte-Electrode Interfaces (TOWNER_20)


## Regina Garcia-Mendez 1, J.Sakamoto[1,2]

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*[2]Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI*


Reducing our dependence on fossil fuel to power the transportation sector can be realized by the development of batteries with high energy density and improved safety. State of the art lithium ion batteries deliver 600 W·h per liter. However, by replacing the graphite anode electrode with metallic lithium, and the flammable liquid electrolyte with a solid, the energy density can be two times higher than the current technology, approaching 1200 W·h per liter. Moreover, safety concerns are mitigated since the solid electrolyte is not combustible. However, little is known about the physics, electrochemistry and mechanics of the Li-Solid Electrolyte interface. For example, it has been observed that under certain conditions relatively soft Li metal can penetrate a relatively hard ceramic electrolyte short circuiting the cell. This work proposes a mechanism from a quantum mechanics perspective by which lithium metal penetrates the solid electrolyte consequently fracturing the electrolyte and causing short circuiting. To validate this hypothesis, the model interface Li metal-Lithium Lanthanum Zirconium Oxide (LLZO) Solid Electrolyte was studied under controlled charging conditions. LLZO is a unique model system that is stable against lithium and its lithium ion conductivity is higher than liquids at room temperature. An advanced cell was designed, developed and tested to measure the stability of the Li-LLZO interface under dynamic conditions (electrical current). It was determined that the Li-LLZO Solid Electrolyte at potentials of -0.02 V and below Li metal penetrates, which is in between what has been predicted by thermodynamics (+0.05 V vs Li[1]) and quantum mechanics of -0.2 V vs Li[2]. The results of this work can elucidate what controls the stability of the Li-Solid electrolyte interface, and therefore enabling safe, higher energy density solid-state batteries.


1. Mo, Y. et al. 2016. J. Mater. Chem. A. 4, 3253-3266.
2. Thompson, T., et al. (2017).. *ACS Energy Letters*, *2*(2), 462-468

## Anticipating Bifurcations for Identifying Dynamic Characteristics of Complex Systems (TOWNER_22)


### Amin Ghadami, Bogdan I. Epureanu

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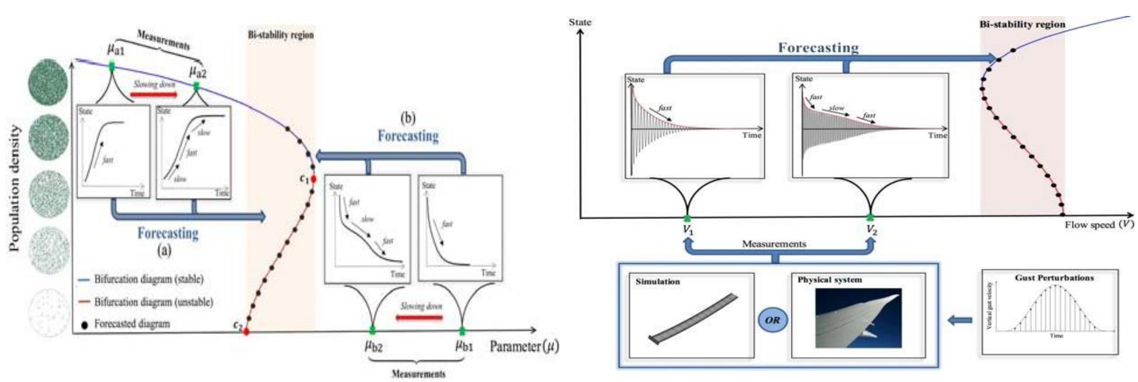
It is becoming increasingly evident that many complex systems are at risk of critical transitions at which the system shifts abruptly from one state to another when a threshold is crossed. Recent studies have revealed that a variety of systems, ranging from systems examined by engineering, physics, and biology, to others related to climate sciences, medicine, social sciences, and ecology are susceptible to transitions leading to drastic re-organization or collapse. Such an unexpected transition is usually undesirable, because it is often difficult to restore a system to its pre-transition state once the transition occurs. It is exceedingly difficult for us to know if a system comes close to critical transitions since we simply do not see any noticeable change of the situation unless the transition happens. Furthermore, for real world complex systems, accurate models are in general not available, and predictions based on models of limited accuracy face substantial difficulties. Hence, we are still badly equipped to predict critical transitions and there is an acute need for reliable methods to predict such catastrophic events as part of a preventive plan against possible detrimental consequences.

In this research, I introduce a model-less approach to forecast critical points and postcritical dynamics of complex systems using measurements of the system response collected only in the pre-transition regime. The method is employed to forecast 1) flutter instability in fluidstructural systems, and 2) collapse of natural populations in ecological systems, as two important classes of complex systems. The exciting theoretical and experimental results of this study address some of the most important challenges in forecasting safety and stability of complex systems. We highlight that by monitoring the system's response to perturbations in the pretransition regime, it is possible to gain crucial information about the future system's safety and stability, such as distance to upcoming transition and future system equilibriums, which makes our method a unique tool for stability analysis of complex systems. This effort answers important challenges which impact applications spanning from engineered to ecological systems where maximum safety and performance is desired.




(a) (b)

Schematic of the forecasting method for (a) aeroelastic systems and (b) natural populations. Bifurcation diagrams are forecasted by measuring a limited number of system responses to perturbations before the instability boundary. As the system approaches a bifurcation, the rate of system's recovery is decreased. Theoretical and experimental results confirm that by monitoring the system's response to perturbations in the pre-transition regime, it is possible to forecast future stability of complex systems.

# Emulation of BOR-60 Irradiated T91 Using Dual Ion Beam Irradiation (TOWNER_24)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Prediction of material response to high irradiation damage levels is a key challenge facing the nuclear energy industry for the life extension of current reactors and the development of advanced reactors. Ion irradiation is the only viable means to conduct accelerated materials evaluation using high damage rates to achieve high damage levels (measured in displacements per atom or dpa) with relatively low cost, little to no induced radioactivity, and primary damage events comparable to neutron irradiations. Radiation damage induced microstructural changes include dislocation loops of displaced planes in the crystalline structure, cavities that lead to swelling and dimensional changes of the material, the segregation of solute atoms to boundaries of the crystalline structure, and the accumulation of solutes into clusters distinct from the surrounding crystalline structure. These defects influence the mechanical behavior of the irradiated material and consequently, the expected lifetime of a reactor component. As a ferritic- martensitic steel, alloy T91 is one of the candidate materials for high dose structural components because of its resistance to swelling compared to austenitic steels. Dual ion irradiation was performed on T91 using $Fe^{2+}$ ions to induce damage and co-injected with $He^{2+}$ ions to simulate transmutation gas buildup in a temperature range from 406°C to 570°C at 14.6-16.6 dpa and 445°C at 35 dpa to compare with the same alloy irradiated in a test reactor at similar temperatures and dpa. The resulting microstructures were characterized using transmission electron microscopy (TEM), scanning transmission electron microscopy (STEM) and energy dispersive x-ray spectroscopy (EDS). Dislocation loops were observed from 406°C to 510°C with increasing diameter and decreasing density with increasing temperature. At higher temperatures of 520°C and 570°C, only line dislocations were found. Swelling exhibited the expected bell-shaped trend with temperature at 17 dpa following primarily from the density of cavities, peaking at 460°C. Nickel and silicon rich clusters formed under dual ion irradiation near the surface at 406°C, 432°C, 445°C and 460°C, but not at higher temperatures of 520°C and 570°C. Very little Cr and Si segregation was observed at lath boundaries while Ni enriched at all examined temperatures. Segregation of Cr and Ni appeared to saturate by 17 dpa, while Si enriched up to 35 dpa. A temperature shift of 60°C-70°C was found to equate the microstructures of dual ion irradiated T91 and T91 irradiated in a test nuclear reactor for dislocation loops and cavities. However, segregation to grain boundaries and formation of nickel-silicon rich clusters was insignificant in the dual ion irradiated T91 at these temperatures. These results are discussed in the context of microstructure invariance theory relationships involving damage rate and temperature.

# Geofencing In Complex Low-Altitude Airspace (TOWNER_26)


## Mia N. Stevens, Ella M. Atkins

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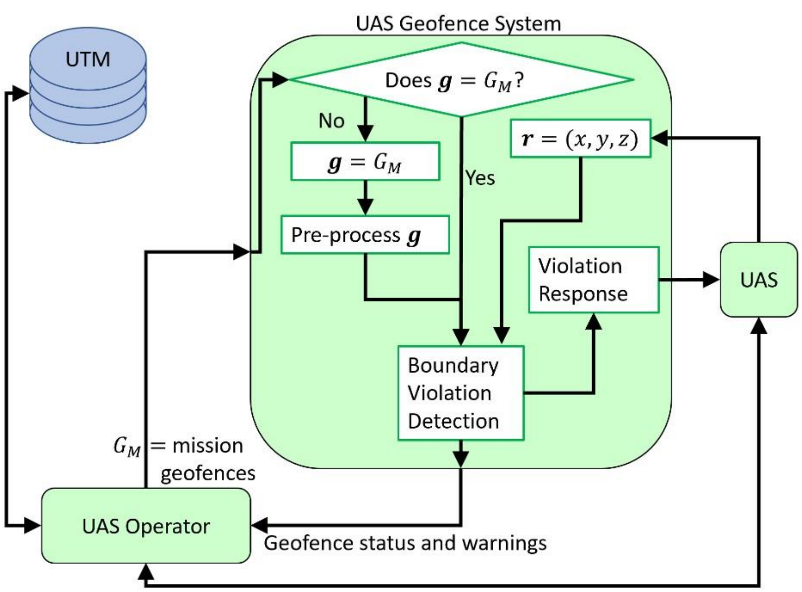
As numerous and diverse unmanned aircraft systems (UAS) are given permission to enter the airspace, increasingly capable UAS Traffic Management (UTM) and safety systems will be needed. A key component of UTM is the presence of assured geofence systems onboard each UAS. Geofences partition the airspace into usable airspace (keep-in geofences) and no fly zones (keep-out geofences) for each UAS. However, these geofencing systems do not yet exist. This work proposes a standard definition of a geofence and develops algorithms for enforcing and coordinating the geofences. A diagram of the geofencing system is shown below.

With the geofence defined, we design three categories of algorithms to enforce the geofence on the UAS: preprocessing of the geofence, geofence boundary violation detection, and geofence boundary violation response. The preprocessing algorithms modify the geofence boundaries to account for the stop distance of the UAS and other considerations such as wind and sensor noise. The boundary violation detection algorithms quickly determine when the geofence has been violated, and the violation response algorithms generate control commands to prevent or correct the detected violation. The geofence system only modifies the nominal UAS guidance and control commands when the UAS violates the geofence boundaries.

To coordinate the geofences of individual UAS and operators, there is a data connection between the UAS operators and the UTM system, which maintains a list of all active geofences. This connection analyzes the new and existing geofences to check for conflicts and keep the UAS operators informed about existing relevant geofences. Together, the UTM system coordination of geofences and the UAS geofencing system algorithms, form a system for the safe incorporation of UAS into the airspace.



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