Abstract Booklet

10th Annual Engineering Graduate Symposium

Friday, October 30, 2015

College of Engineering, University of Michigan, Ann Arbor
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Info session
October 30, 2015
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Abstracts – Morning Session
ACS: Atmospheric and Climate Science
Performance Testing of an ASIC 64x64 Coarse Digital Correlator for Synthetic Aperture Radiometry

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¹Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI
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Proposed approaches to the National Research Council Earth Science Decadal Survey’s Precipitation, All-Weather Temperature and Humidity mission involving synthetic aperture arrays require massively parallel, high speed correlators implemented on a geostationary satellite platform. We present the testing methods and results of a 2-bit 64x64 channel digital correlator chip using a low-power ASIC architecture. The chip was designed in the Electrical Engineering and Computer Science Department of the University of Michigan. The course digital correlations performed by the ASIC must be mapped to analog correlations for an inverse 2-D Fourier transform to generate T_B images. The quality of these correlations strongly influences the NEΔT of the synthesized images. Several key figures of merit express the correlation quality. The correlation efficiency of mapped analog correlations must be high, frequency response across the IF passband must be reasonably flat, and isolation between neighboring input channels must be small enough to be either negligible or correctible in data processing. A series of tests have been developed to measure these figures of merit of the ASIC using a two-channel arbitrary waveform generator. Measurements of the system’s correlation efficiency and frequency response meet design requirements. Nearest-neighbor analog input isolations are within correctible levels. Three of the ASIC correlators are currently integrated into a Geostationary Synthetic Thinned Aperture Array instrument prototype in testing at NASA’s Jet Propulsion Laboratory. Other potential implementations exist in synthetic aperture radiometers for a variety of applications in Earth science and radio astronomy.
Using Chlorophyll Fluorescence to Assess the Impact of Agriculture on Northern Hemisphere CO₂ Seasonality

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The seasonality of carbon dioxide (CO₂) concentrations in the northern hemisphere (NH) has increased by up to 50% over the previous five decades. A significant portion of this increase may be explained by enhanced agricultural productivity. The impact that increased crop production has on CO₂ seasonality is dependent on the fraction of the crop Gross Primary Product (GPP) that occurs during the natural carbon uptake period (CUP). Solar Induced Fluorescence (SIF), an artifact of photosynthesis, can be used to assess GPP directly via remote sensing. New methods for measuring SIF from space provide tools for obtaining GPP data at regional and global levels. We use SIF data from the GOSAT and OCO-2 satellites to obtain observational estimates of the fraction of GPP occurring within the CUP in NH agricultural regions. We compare these fractions with estimates made using crop calendars and inventories and, where available, with CO₂ flux data from eddy covariance towers. Our results offer insight into the impact that increased agricultural productivity has on the seasonal amplitude of NH CO₂ concentrations.
Parameter Uncertainty on AGCM-simulated Tropical Cyclones

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This work studies the parameter uncertainty on tropical cyclone (TC) simulations in Atmospheric General Circulation Models (AGCMs) using the Reed-Jablonowski TC test case, which is illustrated in Community Atmospheric Model (CAM). It examines the impact from 24 parameters across the physical parameterization schemes that represent the convection, turbulence, precipitation and cloud processes in AGCMs. The one-at-a-time (OAT) sensitivity analysis method first quantifies their relative importance on TC simulations and identifies the key parameters to the six different TC characteristics: intensity, precipitation, longwave cloud radiative forcing (LWCF), shortwave cloud radiative forcing (SWCF), cloud liquid water path (LWP) and ice water path (IWP). Then, 8 physical parameters are chosen and perturbed using the Latin-Hypercube Sampling (LHS) method. The comparison between OAT ensemble run and LHS ensemble run shows that the simulated TC intensity is mainly affected by the parcel fractional mass entrainment rate in Zhang-McFarlane (ZM) deep convection scheme. The nonlinear interactive effect among different physical parameters is negligible on simulated TC intensity. In contrast, this nonlinear interactive effect plays a significant role in other simulated tropical cyclone characteristics (precipitation, LWCF, SWCF, LWP and IWP) and greatly enlarge their simulated uncertainties. The statistical emulator Extended Multivariate Adaptive Regression Splines (EMARS) is applied to characterize the response functions for nonlinear effect. Last, we find that the intensity uncertainty caused by physical parameters is in a degree comparable to uncertainty caused by model structure (e.g. grid) and initial conditions (e.g. sea surface temperature, atmospheric moisture). These findings suggest the importance of using the perturbed physics ensemble (PPE) method to revisit tropical cyclone prediction under climate change scenario.
An Analysis of Wind Gusts and the Effect on Electrical Outages Based on Season in Southeast Michigan

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Severe weather and wind can cause major impacts on electrical outages in Southeast Michigan. It is important to be able to forecast these weather risks in advance in order to better prepare for outages, damage, and public safety. Peak wind speeds from wind storms and thunderstorms affect areas differently based on their geography, tree density, and season. When trees have leaves on their branches, they are heavier, tend to hang lower, and be more susceptible to breakage. This study uses DTE Energy outage data during storms from 2003 to May 2015 and wind data from KDTW and KFNT to explore the relationship between wind gusts and power outages in Southeast Michigan. From May to September vegetation coverage is high and from October to April vegetation coverage is low. Completing a regression analysis for these two periods separately for each year shows that the threshold for wind gusts vs. outages is actually lower between May and September, which results in more outages at lower wind gusts. Between October and April when trees have less coverage, they can withstand stronger gusts during windstorms, therefore holding the integrity of the electrical system and resulting in fewer outages. This distinction can help electrical companies, such as DTE Energy, enhanced their planning strategies in the summer and winter months in Southeast Michigan for weather and storms.
Investigating the effects urban aerosols have on a mesoscale convective system

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Urban regions can modify thunderstorms by changing storm morphology and precipitation patterns. The Great Plains of the United States experiences frequent severe weather, and cities in this region are surrounded by agriculture, meaning regional aerosols are a combination of anthropogenic urban and agricultural sources. This study examines the effects of urban plume aerosols have on a mesoscale convective system (MCS) in the Central Great Plains with the Weather Research and Forecasting Chemistry model (WRF-Chem). Kansas City, MO emissions were scaled by factors of 0.5, 1.0, and 2.0 to investigate the impact of urban aerosol load on MCS propagation and strength. First we determine the changes in aerosol magnitude. Then we analyze the changes in storm morphology, spatial accumulated precipitation, and precipitation rates. We then examine the microphysical processes via hydrometeor growth and phase change. Cold pool strengths determine the propagation and development of squall lines, and are partially a function of microphysical processes and are directly influenced by aerosol load. We connect the microphysical changes to the large-scale changes and that aerosols within an urban plume can enhance or suppress precipitation depending on the time within the storm development and the relative magnitude of aerosol load.
During NASA’s Genesis and Rapid Intensification Processes (GRIP) field campaign, the Hurricane Imaging Radiometer (HIRAD) and the Stepped Frequency Microwave Radiometer (SFMR) were flown on separate aircraft to acquire observations of Hurricane Earl (2010). While the engineering aspects of each instrument are different, both of these instruments allow for retrievals of rain rate and surface wind speed in tropical cyclone conditions. Initial retrieval algorithm development for HIRAD was based on well-established SFMR retrieval algorithms. Initial comparisons of collocated HIRAD/SFMR observations showed that assumptions possible in the SFMR retrieval algorithm are not possible for HIRAD’s retrieval algorithm. Comparisons of HIRAD/SFMR rain rate retrievals motivated the development of the Coupled-Pixel Model (CPM) atmospheric retrieval algorithm for HIRAD. Results from the application of the CPM method to Hurricane Earl (2010) observations will be presented.
Monte Carlo photon modeling to explore the dependance of snow bidirectional reflectance on grain shape and size

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The spectral albedo of a snow-covered surface is sensitive to effective snow grain size. Snow metamorphism, then, affects the strength of surface albedo feedback and changes the radiative energy budget of the planet. The Near-Infrared Emitting Reflectance Dome (NERD) is an instrument in development designed to measure snow effective radius from in situ bidirectional reflectance factors (BRFs) by illuminating a surface with nadir positioned light emitting diodes centered around 1.30 and 1.55 microns. Better understanding the dependences of BRFs on snow grain shape and size is imperative to constraining measurements taken by the NERD. Here, we use the Monte Carlo method for photon transport to explore BRFs of snow surfaces of different shapes and sizes. In addition to assuming spherical grains and using Mie theory, we incorporate into the model the scattering phase functions and other single scattering properties of the following nine aspherical grain shapes: hexagonal columns, plates, hollow columns, droxtals, hollow bullet rosettes, solid bullet rosettes, 8-element column aggregates, 5-element plate aggregates, and 10-element plate aggregates. We present the simulated BRFs of homogeneous snow surfaces for these ten shape habits and show their spectral variability for a wide range of effective radii. Initial findings using Mie theory indicate that surfaces of spherical particles exhibit rather Lambertian reflectance for the two incident wavelengths used in the NERD and show a monotonically decreasing trend in black-sky albedo with increasing effective radius.
Simulated Transport of Pollen Produced by an Offline, Observation-based Emission Model

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\textsuperscript{1}Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI

Atmospheric pollen emitted from trees and grasses exhibits both a high temporal variability and a highly localized spatial distribution that has been difficult to quantify in the atmosphere. While observations are sparse and therefore unsuited for regional-level analysis, we turn to modeling to help determine airborne pollen distributions over the continental United States. We use existing pollen counts from 2003–2008 across the continental U.S. in conjunction with a tree database and historical meteorological data, as well as genus-level morphological data, to create an observation-based phenological model that produces accurately scaled and timed emissions. These emissions are emitted and transported within the regional climate model (RegCMv4) and the resulting time series are compared with National Allergy Bureau site-by-site observed pollen counts. Obtaining accurate airborne pollen burdens will allow the computation of radiative effects in RegCM leading to an assessment of the interactions of pollen aerosol with the climate.
ATE: Automotive and Transportation Engineering
Sharing Control Between Humans and Automation System

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This study presents a paradigm to determine the features of control sharing between human operators and automation systems in steering a ground vehicle. The design consists of a racing Baja car which communicates with a fixed-based haptic steering wheel using a two way radio. In this study, the human operator drives the Baja car while the automation system assists the driver through the haptic steering wheel. In this shared control system, the human operator and the automated system have their own control intentions. Specifically, the aim of the automated system is to steer a vehicle along a pre-defined path while drivers were asked to follow the predefined path as closely as possible without colliding with any of the pre-defined obstacles. Additionally, the drivers were given a secondary task (reading a series of numbers) while driving the vehicle. The experimental results indicate that by accurately sharing control authority, fewer automation mistakes will take place and safety will be increased.
Quality-Driven Carshare Fleet Allocation under Uncertain One-Way and Round-Trip Demands

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Carsharing has seen increased usage in recent years due to increasing car ownership costs and awareness of environmental issues. In this paper, we consider a problem of allocating a carshare fleet to contracted locations to maximize the total profit of operating shared cars under random customer demands. We consider this as a two-stage model: the first-stage allocates the fleet, and the second optimizes expected profits and penalties due to unsatisfied demand given this allocation. One-way and round trips, and ad-hoc relocation of vehicles by the user are allowed. The second-stage is a minimum cost flow problem on a spatial-temporal network constructed from given one-way and round-trip demands in each independent scenario. We penalize the number of lost customers to encourage higher quality of service, and also consider a risk-averse variant of the second-stage model that minimizes the conditional value-at-risk of unsatisfied demands. We optimize the two-stage stochastic integer program using a branch-and-cut algorithm with mixed integer rounding on Benders cuts and give insights on carsharing location design and operations by testing instances generated from real data reported by Zipcar in the Boston area.
Vehicle and Drive Cycle Simulation of a Vacuum Insulated Catalytic Converter

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A GT-SUITE vehicle-aftertreatment model has been developed to examine the cold-start emissions reduction capabilities of a Vacuum Insulated Catalytic Converter (VICC). This converter features a thermal management system to maintain the catalyst monolith above its lightoff temperature between trips so that most of a vehicle's cold-start exhaust emissions are avoided. The VICC thermal management system uses vacuum insulation around the monoliths. To further boost its heat retention capacity, a metal or salt phase-change material (PCM) is packaged between the monoliths and vacuum insulation. The GT-SUITE model successfully incorporated the transient heat transfer effects of the PCM using the effective heat capacity method. A variety of conventional, stop-start and hybrid electric vehicles have been simulated over standard drive cycles using this model. For each vehicle, prep-cycle simulations were followed by soak simulations of differing time periods. Model predictions show that the VICC was able to maintain converter temperatures above 300°C for at least 12 hours for all of the simulated vehicles and standard prep-cycles. Furthermore, this heat retention ability directly translated to a proportional reduction in cold-start exhaust emissions. With the introduction of intermediate soak times as part of the EPA emissions test regulations, the benefits of the VICC should be seen in all standard drive cycle emissions tests. The simulation results of the GT-SUITE model demonstrate the contribution of the Vacuum Insulated Catalytic Converter in meeting stringent future emission standards.
Passive Ammonia SCR After-Treatment System Evaluation for a Gasoline Engine Operating on Conventional and Advanced HCCI and SACI Combustion Modes

Jordan Easter\(^1\), Stani Bohac\(^1\)

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Advanced engine combustion strategies, such as HCCI and SACI, allow gasoline engines to achieve high levels of thermal efficiency with low levels of engine-out NO\(_x\) emissions. However, a modest NO\(_x\) reduction is still necessary to meet current and future emissions regulations. Typically, this is handled with a TWC; however, lean operation prevents the TWC catalyst from functioning properly. One potential solution suggested in the research community for handling this challenge without the addition of costly NO\(_x\) traps or on-board systems for urea injection is the passive TWC-SCR concept. This concept includes the integration of an SCR catalyst downstream of a TWC and the use of periods of rich operation to generate NH\(_3\) over the TWC to be stored on the SCR catalyst for use in NO\(_x\) reduction during lean operation. A laboratory study was performed with a modified 2.0 L gasoline engine that was cycled between lean HCCI operation and rich SACI operation and between lean and rich conventional spark ignited combustion to evaluate the emissions reduction potential of a TWC-SCR system. To complete the investigation, the lambda value during rich operation and the time held in rich operation were varied for each test and for both combustion modes. An FTIR analyzer and two fast response NDIR analyzers were used to evaluate the generation of NH\(_3\) over the TWC during the rich operation, the storage of NH\(_3\) by the SCR catalyst during rich operation, and the reduction of NO\(_x\) over the SCR catalyst during lean operation.
Near-wall Flow Measurements in a Canonical Internal Combustion Engine

Mark L. Greene¹, David L. Reuss¹, and Volker Sick¹

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High frame rate PIV has been used to measure the near-wall velocity fields in a 6 mm field of view through the cylinder and below the flat head of a canonical internal combustion engine under both motored and fired operating conditions. This paper primarily outlines the solutions to challenges encountered in acquiring the near-wall high-resolution PIV data due to particular geometric constraints of a reciprocating internal combustion engine. The methods used here allowed velocity measurements within 0.2 mm of the wall with a vector spacing of 0.1 mm and spatial resolution of 0.2 mm. The instantaneous velocity measurements demonstrate the variety of different flow structures that interact with the near wall region in internal combustion engines, which are markedly different from canonical steady-flow boundary layers. Instantaneous flow structures adjacent to the wall are shown to include rotational structures, wall-normal jets, and shear layers within approximately 1 mm of the wall. The influence of the wall on the ensemble-averaged and -rms wall normal velocity component extends much farther from the wall than the same influence on the wall-parallel velocity component, consistent with DNS results performed by other researchers in a different canonical engine. The fired test results demonstrate the ability to measure the near-wall flow in the unburned-gas ahead of the flame, and the implicit conditional sampling when using combustible particles.
Dynamical Analysis and Optimization of Heterogeneous Connected Vehicle Systems

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Advanced driver assistance systems (ADAS) have been used to improve vehicle safety and passenger comfort in the last couple of decades. Vehicle-to-vehicle (V2V) communication has the potential to further enhance the performance of these systems by allowing the vehicle to monitor a larger traffic environment. Recently, connected cruise control (CCC) was proposed to regulate the longitudinal motion of vehicle, which utilizes V2V information broadcast by multiple vehicles ahead. This can be used to improve traffic conditions even with low penetration of CCC vehicles. It can relieve the problem of traffic jam by making traffic flows smoother on one hand. Smoother traffic flow can potentially lead to better system-level fuel economy on the other hand. When mixing CCC vehicles to the flow of human-driven vehicles, a hybrid system is created since human-driven vehicles operate in continuous time while CCC vehicles are controlled by digital controllers. We investigate stability and disturbance attenuation in such heterogeneous systems and optimize CCC controllers to achieve best fuel economy. This way, the benefits of CCC can be quantified at the vehicle as well as at the system level.
Composite Adaptive Internal Model Control and its Application to Boost-Pressure Control of a Turbocharged Gasoline Engine

Zeng Qiu¹, Jing Sun², Mario Santillo³, Mrdjan Jankovic³

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³Ford Motor Company, Dearborn, MI

Internal model control (IMC) offers an intuitive control structure and simple tuning philosophy, which makes it appealing to industrial applications. It has a plant model and its approximate inverse as explicit components of the controller. An innovative approach is taken to express the IMC tracking error as the sum of the plant modeling error and the plant right-inverse modeling error. For a nonlinear and high-order plant, designing a plant model and its inverse presents a great challenge. We propose composite adaptive IMC (CAIMC) that uses linear models to capture the plant dynamics and the plant right-inverse dynamics though simultaneous identifications. The simultaneous identifications minimize the plant modeling error and the plant right-inverse modeling error respectively, and further reduce the IMC tracking error. The advantages of CAIMC are demonstrated on the boost-pressure control problem of a turbocharged gasoline engine. The design of the CAIMC assumes that the plant model and its inverse are represented by the first-order linear dynamics. The unmodeled dynamics and uncertainties due to linearization and variations in operating conditions are compensated through adaptations. The resulting CAIMC is first applied to a physics-based high-order and nonlinear proprietary turbocharged gasoline engine model, and then validated on a 2.0L Ford Explorer EcoBoost vehicle. Both the simulation and experimental results show that the CAIMC cannot only effectively compensate for uncertainties but also auto-tune the IMC controller for the best performance.
Constructing User Specific Probabilistic Models of Driver Input via Maneuver Recognition

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Semi-autonomous active safety systems have the potential to dramatically improve the safety of existing transportation systems. These systems rely upon correctly predicting a driver’s input in order to determine when automated intervention is required. In this work, the authors propose a multi-level hierarchical model that generates probabilistic predictions of a driver’s input over a fixed time horizon from data. To accomplish this task, it is hypothesized that a driver’s behavior is composed of sequences of driving maneuvers, each composed of simple actions which are each characterized by a specific input. These distinct maneuvers are encoded at the highest level of the hierarchy while the sequences of actions that produce these maneuvers are encoded at the midlevel. The lowest level of the hierarchy describes the specific inputs that encode each action. To build a probabilistic model of driver input, each trajectory is transformed automatically into a sequence of maneuvers. Each action is assumed to occur for a particular time duration with features associated with the action following certain probability distributions. Transition probabilities between states can be estimated at both the maneuver and action level by employing Markov chain structures. Thus, any given trajectory data can be coded into a sequence of actions. By code-chunk identification we can identify the maneuvers happening.

To validate the performance of this proposed driver modeling scheme, the authors plan to use the IVBSS Database provided by UMTRI.
A Scaled-down Testbed for Modeling Connected and Automated Vehicles Systems

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Built upon vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications enabled by dedicated short-range communication (DSRC) technology, connected and automated vehicles (CAV) systems are expected to reduce traffic delay, congestion level, fuel consumption, and improve safety. However, the existing research is mostly through either high-cost production car experiments or numerical simulations which might not reflect the effects of some key factors such as delays and package loss. This study aims to develop an economic and flexible scaled-down testbed to simulate connected and automated vehicles systems. It primarily includes 1) developing the hardware platform which consists of smart cars and simulated infrastructures, 2) applying adaptive cruise control (ACC) and V2V cooperative adaptive cruise control (CACC) to the smart vehicles and collecting data when conducting experiments and 3) numerically simulating the traffic under ACC and CACC conditions and comparing the results with the experiments to verify the reliability of the platform. As part of the results, the phantom traffic jam is excited and then eliminated in the testbed without bottleneck. This testbed paves the way for not only developing scaled-down CAV testbeds, but also designing CAV systems in the real world.
Battery State of Health Monitoring by the Estimation of Side Reaction Current Density

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This project introduces a method to monitor battery state of health (SoH) via estimating the side reaction current density, a health-relevant electrochemical feature. Battery state of health estimation is a critical part of battery management because it allows for balancing the trade-off between maximizing performance and minimizing degradation. In this project, a health-relevant electrochemical variable, the side reaction current density, is used as the indicator of battery SoH. An estimation algorithm is required due to the unavailability of the side reaction current density via noninvasive methods. In this project, Retrospective-Cost Subsystem Identification (RCSI) is first used to estimate the side reaction current density via identification of an unknown battery health subsystem that generates the side reaction current density. The simulations show promising results in the estimation of the side reaction current density with RCSI under ideal conditions. Then the performance of the algorithms under different types of non-ideal conditions, i.e., measurement noise, modeling errors, and State of Charge (SoC) estimation errors, is examined to test the robustness of the algorithm. The analyses show that the estimation of the side reaction current density using RCSI can be sensitive to the non-ideal conditions that cause battery voltage errors. A new subsystem identification algorithm, Two Step Filter (TSF), is developed to estimate side reaction current density under one type of non-ideal conditions, SoC estimation errors. The simulation result shows that TSF can successfully track the side reaction current density despite the presence of an SoC estimation error of 1%.
CPH: Chemical Physics
Isotropic self-assembly models for anisotropic convex shapes

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The self-assembly process of nano particles into complex structures is governed by specific enthalpic and entropic interactions between the building blocks. To date, it is not generally possible to deduce the required interactions that will lead to the assembly of a specific targeted structure. It was shown in previous work that hard convex polyhedra, that means particles with pure entropic interactions, exhibit very diverse self-assembly behavior into various complex structures. As the interaction range is zero, the structures found are functions of shape alone. In this work we attempt to model the complex anisotropic interactions of these shapes with enthalpic but isotropic interaction potentials derived with the Multi-State Iterative Boltzmann Inversion (MS-IBI). Features identified in these potentials are correlated with shape and structure characteristics and thus serve as predictors for the generalized relationship of shape and structure from self-assembly. The knowledge gained in this way can be used to design assembly protocols for desired target structures. For this purpose the MS-IBI method was first implemented for the in-house particle simulation software hoomd-blue and then validated with a reference system consisting of Lennard-Jones particles. Target configurations for the derivation of isotropic pair potentials are generated by free energy minimization through Metropolis Monte-Carlo sampling of shapes at different packing fractions, where each packing fraction defines one state point. Finally, the potential functions are derived through the parallel iterative improvement of an initial guess obtained through the Boltzmann inversion of each target’s pair radial distribution functions.
Plasmon-induced reconstruction of Ag-Pt bimetallic hollow nanoparticles under oxidation reaction conditions

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The drive to increase product selectivity and conversion of chemical reactions has motivated the exploration of multimetallic nanoparticle catalysts. Often, these materials are susceptible to surface changes under reaction conditions. For example, under oxidation reaction conditions, the more oxophilic metal may preferentially enrich on the surface and potentially form a surface oxide. This phenomenon hinders the use of multimetallic nanoparticles as oxidation catalysts. Here, we demonstrate that visible light can be used to reduce surface oxidation and influence the surface composition of bimetallic plasmonic alloys under ethylene oxidation conditions. We synthesize high energy hollow Ag-Pt nanostructures that are inherently more susceptible to surface oxidation. These nanostructures undergo surface oxidation under ethylene oxidation conditions showing poor activity and no selectivity towards the partial oxidation product, ethylene oxide. Excitation of localized surface plasmon resonance through visible light illumination reduces platinum surface oxides allowing the nanostructure to reconstruct resulting in a metal alloy particle. The new alloy surface results in higher ethylene conversion and good selectivity for ethylene oxide. In future studies, plasmon-mediated surface reduction could be used to perform oxidation reactions on metal alloy surfaces instead of metal oxides enabling new surfaces to be explored for oxidation reactions.
Using SERS to shed light on the mechanism of photocatalytic enhancement in plasmonic systems

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Plasmonic metal nanoparticles (Ag, Au, Cu) have long been popular catalysts for a number of important reactions. Yet it was only recently shown these catalytic processes can be altered or enhanced when the system is illuminated with particular frequencies of visible light. These changes in catalytic behavior are driven by the excitation of localized surface plasmons (LSP). The interaction of LSP with surface adsorbates can lead to an injection of charge carriers (e⁻/h⁺) into adsorbates, resulting in chemical transformation. The mechanism of the charge injection process has to this point not been well understood. Here, we couple surface enhanced Raman spectroscopy (SERS) of select probe molecules, with analysis of photocatalytic reaction rates to shed further light on the enhancement mechanism. Our results indicate that localized LSPR-induced electric fields result in photon absorption and a direct charge transfer between metal nanoparticle and reactive adsorbate. These observations provide a foundation for the development of plasmonic catalysts that can selectively activate targeted chemical bonds. The mechanism allows for tuning plasmonic nanomaterials in such a way that illumination can selectively enhance particular chemical pathways.
Using Depletion to Tune Colloid Shape for Assembly

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The depletion interaction is one well-known way to induce aggregation in colloidal systems, but how it can induce solid formation with anisotropic particles is not particularly well understood. Here we use cuboctahedra and penetrable hard sphere depletants as a model system to study how varying depletion size and concentration affects self-assembly with anisotropic particles. In these systems, we can selectively control the assembly of the cuboctahedra into simple cubic and body centered cubic lattices. We explain the stability of the distinct crystals formed via depletion using free energy calculations that consider the contribution of the colloid and depletant entropy separately. We further corroborate our analysis by analyzing how the depletant concentration and size affect the emergent directional entropic forces in the system. We propose the use of depletants as a means of easily changing the effective shape of anisotropic colloids.
Stretchable Electronic and Photonic (meta)Materials from Self-Assembled Layers

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Nanoscale science and technologies has been developed tremendously during the last two decades, introducing a variety of nanomaterials with unique properties. However, incorporation of the properties into macroscale functional applications has been limited. An essential challenge is the integration of such unique properties into assemblies for macroscale devices. Here we explore the self-assembly of nanomaterials in solid-state for discovering fundamental understandings of mechanisms and dynamics for various engineering applications. An example of excellent stretchable conductors from self-assembly of nanoparticles (NPs) was first demonstrated. Free-standing stretchable conductors were prepared by layer-by-layer (LBL) assembly. High conductivity and stretchability were observed and the properties originated from dynamic self-organization of NPs. Modified percolation theory to incorporate the self-assembly gave excellent match with experimental data. The recent study, first demonstrated the chiroptical nanocomposites for the applications of metamaterials devices and optoelectronics. They were LBL assembled from NPs and single-walled carbon nanotubes. Chiroptical activities were reversibly tunable by macroscale stresses. S-like non-planar nano-assemblies are responsible for the optical activities and this was confirmed by computational simulations. Solid-state self-assembly at the nexus of mechanics, electronics, and excitonics/plasmonics can be generalized to other nanoscale materials and open new possibilities for composite-based electronic and optic devices.
Shear-enhanced coagulation of uniform and Janus spheres in dilute-sphere limit: A Brownian dynamics simulation approach

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Brownian dynamics simulations are performed to study the binding kinetics in the dilute-sphere limit by considering interactions of two spheres under shear flow across the entire range of Peclet (Pe) numbers, spanning both perikinetic (diffusion-controlled) and orthokinetic (flow-controlled) coagulation regimes. The dilute regime is attained by carrying out two-sphere simulations in periodic boxes of different sizes and aspect ratios and extrapolating toward the infinite box limit. Effects of particle type (Janus and isotropic particles), shear rate, hydrodynamic interactions, and inter-particle potential are explored. We find that rectangular boxes with appropriate aspect ratios overcome a particle “shadow effect” that cannot be overcome with cubic boxes unless huge boxes are used. With rectangular boxes, we obtain converged binding kinetics for the whole Pe number range, while cubic boxes of increasing size allow converged results only in the absence of flow. Results are computed using both realistic interaction potentials and by replacing the potential with a simple cut off gap distance at which binding is deemed to occur. Results agree with several existing reports including Smoluchowski predictions in the zero- and infinite-shear-rate limits, and high-Pe perturbation results of Feke and Schowalter [J. Fluid Mech. 133, 17-35 (1983)] at Pe numbers above 100. Finally, we compute binding times for anisotropic Janus particles which have both repulsive and attractive faces, for a wide range of Pe number.
Dynamic Covalent Assembly of Peptoid-Based Ladder Oligomers by Vernier Templating

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Dynamic covalent chemistries, in conjunction with template-directed assembly, enable the fabrication of extended nanostructures that are both precise and tough. Here, we demonstrate the dynamic covalent assembly of peptoid-based molecular ladders with up to 12 rungs via scandium(III)-catalyzed imine metathesis by employing the principle of vernier templating, where small precursor units with mismatched numbers of complementary functional groups are co-reacted to yield larger structures with sizes determined by the respective precursor functionalities. Owing to their monomer diversity and synthetic accessibility, sequence-specific oligopeptoids bearing dynamic covalent pendant groups were employed as precursors for molecular ladder fabrication. The generated structures were characterized using matrix-assisted laser desorption/ionization (MALDI) mass spectroscopy and gel permeation chromatography (GPC), confirming successful molecular ladder fabrication.
EBS: Engineering in Biological Systems
Development of “Smart” Bone Targeted Micelles for Bone Metastasized Prostate Cancer

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The reason of prostate cancer mortality is not from the primary cancer but spread of the primary cancer cells to distant organs, especially bone. Current bone metastases therapy modalities are not efficient to cure bone metastasis. To address the limitations, we synthesized a bone targeted amphiphilic triblock copolymer, pVTK-poly(ethylene)-b-poly(acrylic acid)-b-poly(methyl methacrylate), which self-assembles in aqueous medium forming nano-sized micelles that can encapsulate CTX in the hydrophobic core. Cross-linkage of PAA blocks using a ketal-linker forms an acid-labile shell, which stabilizes formed micelles at physiologic pH but allows selective release of loaded cargo in acidic environments. Average size of particles was ~100 nm. Further, we investigated optimum bone binding mole percent of pVTK (0, 5, 10%) in the particles using HA-disc, bone powder, and bone-chip relying on FITC fluorescence of the peptide. Percent of bound of 5% and 10% pVTK micelles on HA-discs were 58 and 61, respectively, while the same formulations binding percentage on rat bone powder were 42 and 38, respectively. Furthermore, CTX loading efficiency of 5 and 10% pVTK-micelles were around 26.0 and 18.8%, respectively. Cytotoxicity results of the particles showed pVTK-micelles (0, 5, 10%) did not have any cytotoxic effect on PC cells. IC₅₀ values of CTX-loaded non-targeted, 5%, and 10% pVTK-micelles were 0.76, 2.46, 0.37 nM, respectively with the control of 0.60 nM free CTX. These results indicate pH-sensitive, CTX-loaded, bone-targeted pVTK-micelles can preferentially bind to bone and achieve tunable CTX release in tumor lesion, which can selectively kill tumor cells while limiting systemic side effects.
Integrated Electrochemical Impedance Spectroscopy Biosensing for the Real-time Monitoring of Immune Cell Cytokine Secretion

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The human immune response is a blanket term given to the interplay between several subsets of immune cells in response to infection or injury. This interplay is mediated by a complex intercellular communication network, which in turn is largely facilitated by soluble signaling proteins called cytokines. At the present time, few tools exist that allow the dynamic monitoring of cytokine secretion from activated immune cells. It is likely the potentiation of immune cells – namely, how quickly and to what extent they secrete cytokines – contains valuable diagnostic information that is currently unexplored. In order to meet this need, this project seeks to create a technique enabling the on-chip capture, enumeration, stimulation, and cytokine secretion profiling of small subpopulations of immune cells. This is accomplished by integrating cell-capturing microfluidics with an electrochemical impedance spectroscopy (EIS) biosensing platform. The developed platform is capable of monitoring secreted cytokine levels rapidly (45 second resolution) and with high sensitivity (pM levels). Cell enumeration is accomplished using an integrated on-chip impedance-based cell counter. Multiple biosensing electrodes can be integrated into a single device, allowing parallel control measurements or multiplexed cytokine detection.
Effect of Core Temperature on Peripheral, Cerebral, and Infrarenal Vasculature in MRI Studies

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The cardiovascular system plays a vital role in thermoregulation, in part because of the influence of convection (movement of blood flow across the vessel walls) and because it regulates flow to and from specific regions. To study rodents with MRI, anesthesia is required, resulting in diminished thermoregulation capability and thus decreased core temperature. Changes in the cardiovascular system due to thermoregulation can be divided into three compartments: core, muscle, and skin. In this study, we quantify geometric changes in the core including peripheral and cerebral arteries, strain and area changes in the infrarenal aorta, and ejection fraction (EF) and cardiac output (CO) at different core temperatures using 3D MR angiography and CINE imaging to: develop methods to study thermoregulation; further understand the effect of temperature on the CV system; and promote use of closely controlled temperatures in rodent studies. Male and female C57BL6 mice were imaged. Data acquisition included hindlimbs (peripheral), Circle of Willis (cerebral), infrarenal aorta, and heart. Data was acquired at these locations at: 35, 36, 37, and 38 °C (+/- 0.1°C). The most drastic change from temperature occurred in the peripheral vessels particularly the saphenous artery. The tracking length increased by 290% in males and 768% in females from 35°C to 38°C. This study provides a novel approach to studying thermoregulation by isolating vascular changes due primarily to temperature from metabolic and behavioral responses. It also advocates for controlling animal temperature during studies which depend on influences from the CV system, e.g. studies of peripheral artery disease.
Ocular infirmities, including glaucoma and presbyopia, could benefit from laser surgery in the sclera. Scleral surgery is difficult, however, because the sclera is highly scattering for most commercial short-pulse lasers. We can overcome this scattering with an optical probe that measures tissue optical properties. This probe delivers laser pulses into the sclera, which converts the frequency of the pulses and delivers the new signal backward out of the tissue by the process of backward-propagating second harmonic generation (B-SHG). We developed a model relating the measured B-SHG signal to tissue optical properties, which can then relate to the laser pulse energy needed for surgery. To test the model, whole porcine eye globes were mounted ex vivo in a custom chamber, and a femtosecond near-IR laser ($\lambda_0=1030$ nm) delivered individual pulses to stimulate B-SHG, which was measured externally with a photomultiplying tube. Low-energy pulses were used to ensure that the probe was non-destructive. After collecting B-SHG data, the laser pulse energy was increased until subsurface surgical incisions were observed. For 26 samples, the pulse energy needed for an incision varied from 2.0–6.5 $\mu$J, and without using this probe, we estimate that the accuracy of scleral surgery could not exceed 44% because of the uncertainty of determining the precise energy needed for an incision. Using information from this probe, however, we could increase the accuracy of scleral surgery to 72%. From this, we can see how B-SHG can serve as an optical probe that could facilitate scleral surgery.
Design of a Simple and Reliable Microfluidic, High-Throughput, Single-Cell Capture Scheme

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In recent years, studies have found significant heterogeneity among tumor cells. In the past these cells were considered as copies of each other. Currently there are many assays and data reported as averages over a large number of cells. However, assumption of all the cells studied being identical may lead to incorrect or imprecise results due to the fact that they may be only a mixture of different cell subtypes. In order to understand the behavior of each cell in heterogeneous groups there is a need for high-throughput assays at single cell resolution. Such assays will tell us the individual properties of thousands of cells. Microfluidic technology has emerged as a state-of-the-art approach for cell biology across many fields. Small sample volumes, precise fluid control, and high throughput scaling enable microfluidic assays for single cell analyses effectively. Currently, single cells can be captured into individual microwells via a hydrodynamic capture mechanism. Although the throughput has increased from tens to hundreds of cells, it is not enough to achieve statistically significant conclusions for rare sub-populations, found in ~1% among the whole population, like cancer stem cells. In this work, we propose a simplified filter based cell capture scheme to achieve 10 thousand microwells in the same device footprint of 4-cm² area. With such a platform, we can study individual cell behaviors, including growth, symmetric/asymmetric division, and treatment resistance. With the high-throughput, even the rare sub-populations can be characterized, providing a more general understanding about the composition and properties of the tumor.
A Miniaturized Hemoretractometer (mHRM) for Blood Clot Retraction Testing

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Blood coagulation is a critical hemostatic process that must be properly regulated to maintain a delicate balance between bleeding and clotting. Disorders of blood coagulation can expose patients to the risk of either bleeding disorders or thrombotic diseases. Coagulation diagnostics using whole blood is very promising for assessing the complexity of the coagulation system and for global measurements of hemostasis. Despite clinic values that existing whole blood coagulation tests have demonstrated, these systems have significant limitations that diminish their potential for point-of-care applications. In this work, we leveraged recent advancements in device miniaturization to use functional soft materials to develop a miniaturized clot retraction assay device termed mHemoRetractoMeter (mHRM). In the mHRM, two doubly-clamped mechanical strain sensing beams made with soft elastomer polydimethylsiloxane (PDMS) were utilized for holding prescribed minute amounts of blood samples while simultaneously measuring clot retraction force during blood clotting. Kinetic curves of clot retraction force obtained by the mHRM were utilized for analysis of different major phases of clot formation and extraction of key blood clotting parameters. Using mHRM, we further conducted whole blood coagulation assays to determine the effect of assay temperature, treatments of clotting agent and pro- and anti-coagulant on clot retraction force development. The mHRM's low fabrication cost, small size, and consumption of only minute amounts of blood samples make the technology promising as a point-of-care tool for future coagulation monitoring.
Two Different Device Physics Principles for Operating MoS\(_2\) Transistor Biosensors and Comparison of MoS\(_2\) and WSe\(_2\) Field-Effect Transistor Biosensors

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We identify two different physics principles for operating MoS\(_2\) field-effect transistor biosensors due to different antibody functionalization sites. If antibodies are functionalized on an insulating layer coated on a MoS\(_2\) transistor, antibody-antigen binding events mainly alter the transistor threshold voltage, which can be described by the conventional capacitor model. If antibodies are directly attached on the MoS\(_2\) transistor channel, the binding events mainly control the ON-state transconductance of the transistor, resulting in the antigen-induced disordered potential in the MoS\(_2\) channel. Furthermore, by comparing MoS\(_2\) and WSe\(_2\) transistor biosensors, we found that WSe\(_2\) sensors show relatively higher linear-regime sensitivities in comparison with MoS\(_2\) sensors, which is attributed to its ambipolar transport character. In addition, the competition between antigen-induced p-doping and surface-scattering effects may be responsible for the sensor behavior transition observed in the p-type branch of the WSe\(_2\) sensor. This work advances the important device physics related to the fabrication and implementation of reliable transistor biosensors based on emerging atomically layered semiconductors.
MRI Characterization of Venous Thrombosis in Murine Models

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Deep vein thrombosis (VT) is an elusive illness affecting an estimated 900,000 people in the US each year, with one third of cases resulting in fatality. Animal models are fundamental in investigating VT due to the limitations in the human pathogenesis timescale. It is known that VT deteriorates vein wall elastic properties by inducing tissue remodeling. In addition, recent work has shown that avoiding the interruption of inferior vena cava (IVC) branches reduces thrombus development, suggesting that flow patterns within the IVC influence thrombus formation and characteristics. However, little is known about vein wall dynamics changes due to VT. This work investigates wall dynamics along the venous system of mice with VT through the use of high field non-contrast MRI. VT was induced in C57BL/6 mice via infrarenal IVC ligation with surgical interruption of all branches (Group 1), or all branches left open (Group 2). MRI sequences were optimized to image the venous system allowing for observation of changes in blood flow patterns. Using MR venography, a system of collateral veins was observed for the first time in mice with VT. Thrombus development and inhomogeneity was studied \textit{in vivo} at days 2, 6, 14, and 21 post IVC ligation using MRI. Mice with VT presented a two-fold increase in the cross sectional area of the iliac veins, with a 30% decrease in the cross sectional area of the suprarenal IVC. Collateral patterns and thrombus volume differed between the two groups, providing much needed insight to understanding and reducing model variability.
Viscoelastic Multicomponent Diffusion in Non-biodegradable Polymeric Matrix Tablets

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A new transport model of drug release from hydrophilic polymeric matrices based on Stefan-Maxwell flux laws for multicomponent transport is developed. Transport due to water-swelling-induced matrix stress is captured by including polymer stress in the total mixing free energy which contributes directly to the diffusion driving force while leading to time-dependent boundary conditions at the tablet interface and the so-called viscoelastic diffusion. The ESM flux law for any given component takes into account the friction exerted by all other species and is invariant with respect to reference velocity, thus satisfying Galilean translational invariance. Our model demonstrates that penetrant-induced plasticization of polymer chains partially or even entirely offsets the steady decline of chemical potential gradients at tablet-medium interface that drive drug release. Utilizing a Flory-Huggins thermodynamic model, a modified form of the upper convected Maxwell constitutive equation for polymer stress and a Fujita-type dependence of mutual diffusivities on composition, depending on parameters, Fickian, anomalous or case II drug transport arise naturally from the model, which are characterized by quasi-power-law release profiles with exponents ranging from 0.5 to 1, respectively. A necessary requirement for non-Fickian release in our model is that the matrix stress relaxation time is comparable to the time scale for water diffusion.
Noise in the Mammalian Cochlea

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The exceptional sensitivity of the human cochlea, coupled with a high signal to noise ratio, makes it an ideal transduction apparatus for hearing. The transverse flow in the sub-ectorial space in the organ of Corti is sensed by the deflection of the inner hair cell stereocilia and coded into neural signals by the inner hair cell. The noise due to thermal fluctuations caused by the viscosity of the fluid in the sub-ectorial gap could be comparable to the response to external stimuli. Experiments show that the quiescent state noise can be on the order of 0.1nm. In the current study, the ectorial membrane was modelled using beam theory with both bending and extensional degrees of freedom. The dispersion relation in the sub-ectorial region was derived and the flow in the gap modelled using asymptotics. The noise spectrum due to the viscous flow around the stereocilia was analyzed using analytics and a threshold on the signal to noise ratio in the detected signal established. This work investigates how the lowest detectable pressure wave compares to the 20 \textmu Pa threshold of hearing.
A neural interface with dorsal root ganglia (DRG) can provide a rich source of sensory neural activity from peripheral limbs and organs. There are presently no devices designed specifically for interfacing with DRG, so penetrating electrode arrays designed for the brain are typically used. A new thin-film electrode array was designed to provide a close fit to the surface of the DRG. The 64-channel electrode array was microfabricated on an ultrathin (3.6 µm) polyimide substrate to provide flexibility to conform to the curvature of the spinal roots (~1 mm radius). The iridium electrode sites (1130 µm²) have varying pitch (25-300 µm), with impedances of 160 ± 24 kΩ at 1 kHz. Functionality of the array was tested in vivo in an anesthetized feline model after a lumbosacral laminectomy. When the array was placed on lumbar DRG, surface tension yielded a contoured fit without the need for additional downward force. Neural activity, either single- or multi-unit, associated with a tactile stimulus was observed on 27 unique channels. The mean signal to noise ratio for these signals, calculated as peak to peak amplitude over three times the noise standard deviation, was 1.85 with a standard deviation of 0.57. Additionally, simultaneous recording of single units was achieved with multiple closely spaced electrode sets, allowing for spatial localization of the signal source. These results demonstrate the ability of this novel surface array to record high-fidelity neural signals at the DRG. Future work will include optimization of the electrode and studies with chronic placement.
Delineating Cell Signaling Architecture using Microfluidics and Computational Modeling

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Biological processes are influenced by the timing of critical signals. Using a microfluidic delivery system with real-time assessment of cellular calcium and Ca\textsuperscript{2+}-regulated transcription factor NFAT and mathematical modeling, we evaluated how the timing of extracellular ligand pulses affects cell signaling events. We found that lesser amounts of ligand stimulation can give more efficient NFAT activation when stimuli are timed appropriately. Mechanistically, the receptor and NFAT transcription factor motifs form a band-pass filter optimized for intermediate frequencies of stimulation. Distinct optima are found for two closely related NFAT isoforms. Computational modeling suggests that the band-pass nature of signaling pathways may be a generic theme. Our findings may facilitate the design of therapeutic interventions and the development of enhanced \textit{in vitro} cell culture protocols.
Analyzing 3-Dimensional Knee Rotations During Running with and without Load Using Inertial Measurement Units


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Rotations across human knees are induced during a broad range of activities like walking, running, jumping, and turning. In these activities, human performance depends critically on these three-dimensional rotations historically evaluated using either goniometer linkages or video motion capture, both of which have limitations. Goniometers either restrict rotation evaluation to one plane whereas video motion capture is expensive, arduous, and sometimes unreliable due to marker occlusion. These limitations render it impossible to recreate knee rotations in many environments, including athletes on the field of play, workers in the workplace, and warfighters in training and combat theaters. Body-worn inertial measurement units (IMUs) are an attractive alternative technology because they are noninvasive and portable. The orientations of two IMUs placed strategically on the thigh and shank can be exploited to measure the three Euler angles across the knee joint. One challenge is resolving the separate sensor frames relative to a common world frame defined using an estimate of magnetic north via magnetometer data, which differs between IMUs. Resultantly, we developed a correction method by imposing an anatomical constraint by assuming the knee rotates largely in flexion/extension. We compare our results using a more limiting assumption (pure sagittal plane motion) and find excellent agreement. Our method is then used to evaluate flexion/extension range of motion for subjects performing a 10-m sprint and a 400-m run with and without load. With load, we observe an average decrease of 17.2°±9.7° for the sprint and 18.9°±8.1° for the run which signals significant gait modification under load.
FAT: Fluid Dynamics, Acoustics, and Thermal Science
Ion Energetics of the Modes of the CubeSat Ambipolar Thruster

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The CubeSat Ambipolar Thruster (CAT) is a novel electrodeless, permanent magnet, helicon thruster designed to increase the ΔV capabilities of nanosatellites to > 1000 m/s. During testing the CAT has exhibited 2 - 3 distinct operational modes on xenon and argon propellant by varying the power and the propellant mass flow rate. By interrogating the thruster plume with a retarding potential analyzer and an emissive probe energetic ion beams were found to be present in some, but not all, of the modes observed. The various modes were demonstrated to be stable over a range of power and propellant flow rates, allowing for control over the ion beam energy and the thruster specific impulse. Additionally, it was observed that in the modes that exhibited an energetic ion beam a second, lower energy peak corresponding to the local plasma potential was present in the ion energy distribution at sufficiently high back pressures (~ 1 x 10\(^{-4}\) Torr, encountered at propellant flow rates > 5 sccm) and > 20 cm downstream. This is likely due to charge exchange collisions between the beam ions and the background neutrals. At conditions below this backpressure a significant ion population at the local plasma potential was not observed.
Remote acoustic sensing of mechanical changes in thin vibrating plates

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Remote measurements of radiated sound from a vibrating structure may be exploited for non-contacting structural health monitoring. In this work, an experimental method for remote acoustic sensing of mechanical changes in thin vibrating plates is presented. The basic concept is to compare the radiated sound from baseline and mechanically modified plates to determine the presence or absence of mechanical modifications. Experimental results are presented for measurements of radiated sound from a 0.3-m-square by 1.6-mm-thick aluminum plate with clamped edges subject to swept-frequency shaker base-excitation in the bandwidth from 100 Hz to 4 kHz. The primary mechanical change considered in this investigation is added mass via magnets. Acoustic signals are collected with a linear array of sixteen microphones and are used to characterize the acoustic radiation from baseline and modified vibrating plates, to determine the thresholds above which mechanical changes can be reliably detected with statistical significance. This binary method of non-destructive evaluation can be extended to other classes of defects, such as holes, cuts (simulated cracks), and changes in the boundary conditions. With the integration of more advanced signal processing techniques, localization of the mechanical changes may be possible as well. [Sponsored by NAVSEA through the NEEC]
High-fidelity Hydrostructural Optimization of a 3-D Hydrofoil

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In recent years, there has been an increasing interest in developing energy efficient marine propulsors due to increasing fuel prices and the desire to reduce the environmental impacts of maritime transportation. In a recent study, the authors extended the previously developed 3-D compressible Reynolds-averaged Navier–Stokes (RANS) solver to solve for nearly incompressible flow, using a low-speed preconditioner. Garg et al., concluded that the high-fidelity hydrodynamic shape optimization can lead to increase in the efficiency (lift to drag ratio) of up to 19%, while avoiding cavitation, for a 3-D tapered NACA 0009 hydrofoil. However, fluids and structures are tightly coupled disciplines in the marine propulsors design, as slight changes in the geometry can lead to significant changes in the hydrodynamic performance and internal stress distributions. Thus, a 3-D design optimization tool for the coupled high-fidelity hydrostructural optimization is required to obtain practical designs. In the present study, an unswept, cantilevered, tapered NACA 0009 hydrofoil is presented as a canonical representation of more complex marine propulsors such as propellers and turbines. For a lift coefficient of 0.65, the high-fidelity hydrostructural optimization leads to increase in efficiency of 9.0% for a tapered 3-D NACA 0009 hydrofoil, while increasing the cavitation inception speed by at least 55% (for an assumed submergence depth of 1m), while satisfying maximum stress constraints. A thorough study of the design space of marine propulsors using the present state-of-art high-fidelity hydrostructural design optimization tool has the potential to drastically improve fuel efficiency and hence reduce CO$_2$ emission, enhance agility, and reduce the structural weight, while ensuring the structural integrity and delaying cavitation inception.
Towards Multidimensional High-Order Computational Fluid Dynamics Methods

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The reliance on computational tools in design and analysis of complex physical problems in various engineering and defense industries has been increasing more rapidly in the last few decades, and this notes the importance of quick adoption of accurate, efficient, and insightful numerical methods. The current widely accepted industry standards for Computational Fluid Dynamics (CFD) production codes are second-order accurate and rely heavily upon one-dimensional Riemann-Problem based physics. While numerous high-order numerical methods are available, most methods either are not readily parallelizable due to the extensive numerical stencil or fail to include essential multidimensionality of problems. We introduce a new class of CFD method for solving conservation laws called Active Flux (AF) method that is a multidimensional, compact stencil support, high-order CFD scheme. It not only seeks to undertake the shortcomings plaguing current CFD production codes, also provides insights into embracing the new era of computational fluid methods. We present important details regarding technical approaches to relieving current limitations of the numerical methods approximating conservation laws. The fundamental philosophy of AF schemes will be discussed in detail; especially focusing on systems of convective conservation. Some details necessary for constructing high-order numerical methods for conservation laws will also be presented, such as nonlinear limiting mechanism for effective high-order flux evaluation. Furthermore, the current challenges and future directions of the project will also be presented.
Role of secondary flows in flow separations associated with 3D SBLI

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Multiple types of unit shock-boundary layer interactions (SBLI) coupled with each other exist in a realistic supersonic air inlet. Their presence and the results of their coupling are responsible for the onset of inlet unstart. One effect of SBLIs on the flow is flow separation, which reduce the effective flow area available in the inlet passage. In this work we experimentally investigate the flow field associated with a highly 3D SBLI that takes place in a low aspect ratio supersonic wind channel used as a simplified model of a supersonic inlet. Stereo PIV measurements were conducted on multiple planes perpendicular to the flow direction in an effort to investigate the cross-sectional structure of flow separation and how it is affected by secondary flows. Various parameters like vorticity, probability of reverse flow, separation strength and friction coefficient were evaluated, and a general flow structure of the SBLI was constructed. Our analyses indicates that separation is more likely to occur in the region where the two strongest vortex systems, the swept shock vortex and the corner vortex pair, interact. In this study we propose a mechanism based on momentum transport due to vortex interactions and adverse pressure jump caused by the shock to explain the observed flow separation.
Prediction of auto-ignition regimes in turbulent reacting flows with thermal inhomogeneities

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The present work investigates auto-ignition characteristics of compositionally homogeneous reactant mixtures in the presence of thermal non-uniformities and turbulent velocity fluctuations. An auto-ignition regime diagram is briefly discussed, that provides the framework for predicting the expected ignition behavior based on the thermo-chemical properties of the reactant mixture and flow/scalar field conditions. The regime diagram classifies the ignition regimes mainly into three categories: weak (deflagration dominant), reaction-controlled strong and mixing-controlled strong (volumetric ignition/spontaneous propagation dominant). Two-dimensional (2D) direct numerical simulations (DNS) of auto-ignition in a lean thermally-stratified syngas/air turbulent mixture at high-pressure and low-temperature conditions are performed to assess the validity of the regime diagram. Various parametric cases are considered that correspond to different locations on the regime diagram, by varying the characteristic turbulent Damköhler and Reynolds numbers. Detailed analysis of the reaction front propagation and heat release indicates that the observed ignition behaviors agree very well with the corresponding expected regimes as predicted by the regime diagram. This demonstrates that the regime diagram provides a comprehensive theoretical understanding of the physical and chemical mechanisms controlling the auto-ignition phenomena.
Broadband Vibration Suppression using Distributed Vibration Absorbers with an E-damping Concept

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When designing structures, highly damped and low weight are both necessary requirements in the aerospace industry. Unfortunately, it is often difficult to achieve both of these properties with a single material. Typically, the additional damping is added to the structure at the end of the design process. This can add up to 20% additional mass to the structure. The proposed structure aims at integrating damping into the design of the structure and making final product a multifunctional material, called a metastructure. This structure uses geometry modifications to create imbedded vibration absorbers. These absorbers can be tuned such that their natural frequency matches that of entire structure similar to the way traditional tuned mass dampers are implemented. The parameters of the absorbers are optimized in order to minimize the $H_2$ norm of the system’s response. This norm is related to the area under the frequency response curve. Additionally, highly damped materials have properties that strongly vary with temperature. To combat the high magnitude vibrations at high temperatures an active vibration control system is utilized. The active system is only activated at these higher temperatures. This helps creates a low-power controller. All of the proposed structures are constrained to have the same mass as the control structure. Thus all reductions in the $H_2$ norm of the system are compared to structure with the same mass. This results in a significant reduction in vibration levels without adding weight to the structure.
Improving High-Order Finite Element Approximation Through Geometrical Warping

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The use of computational fluid dynamics (CFD) during aircraft design and performance analysis has significantly reduced the number of expensive wind tunnel tests. CFD has also enabled analysis of flows that are hard to produce or visualize experimentally. As CFD is used in more applications, accuracy, robustness, and efficiency become paramount. The current workhorse of production-level CFD uses second-order finite volume methods, but it is proving inadequate for increasingly many cases that require high accuracy. Developing robust high-order finite element methods and putting them into production is a possible solution. However, a fair comparison is not possible without adaptive meshing; methods of different order require different meshes to perform optimally. Combining mesh adaptation with output-based error estimation can further improve the performance of high-order finite element methods. The current state of the art for mesh adaptation is an “hp” technique; solution resolution is improved by raising the polynomial order in areas where the solution is smooth and by refining the mesh in areas where the solution is singular or discontinuous. Here, we present a method to further improve current mesh adaptation methods by considering a new refinement technique. This new refinement technique takes advantage of existing infrastructure in high-order methods to “warp” elements for better solution approximation. For scalar advection-diffusion and compressible Navier-Stokes problems, we show that such warped elements offer significant accuracy benefits without increasing degrees of freedom in the system. Furthermore, we show that combining “hp” adaptation and warped elements further improves accuracy without adding much computational cost.
Synthetic Inflow Conditions for Large Eddy Simulations of Spatially Evolving Wall-bounded Flows

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To improve vehicle fuel economy we plan to reduce the aerodynamic drag they experience. The proposed method is to mitigate the flow separation on the rear end of the vehicle by energizing the boundary layer on the roof using passive solid obstacles called vortex generators (VGs). In order to investigate the efficacy of VGs in mitigating flow separation it is important to accurately replicate the spatially evolving turbulent flow conditions on the roof of a car. We have implemented a method developed by Lee et al. [1992] to prescribe a time varying turbulent inflow condition. Prescribing an anisotropic time varying turbulent inflow condition is challenging because it needs to satisfy Navier-Stokes and continuity equations along with exactly matching the mean, root-mean-square velocities and two point correlations. Since, the inflow conditions do not possess all these properties they undergo transition over a certain distance before developing into a realistic turbulent flow field, usually called the “adaptation distance”. The method is being tested on different grid resolutions and the preliminary results look promising. Previous work done on mitigating flow separation using passive VGs indicates that the effectiveness of VGs is influenced by the relative size of the boundary layer thickness to the VG height. Future work involves understanding the dependence of flow separation mitigation when a cube used as a passive VG is placed in a spatially evolving turbulent boundary layer.
Understanding Coaxial Helicopter Rotor Interaction using a Two-Dimensional Unsteady Vortex Method

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The requirement for a high speed helicopter has led to the development of several coaxial rotor helicopters such as the Sikorsky X2. However the aerodynamic environment at high speeds is a cause of significant vibrations. Especially, the aerodynamic interaction between coaxial rotors of helicopters is a complex phenomenon that has not been studied in great detail. In this study, the coaxial rotor system has been simplified into a two dimensional problem, where two vertically separated airfoils cross each other. An unsteady inviscid potential flow vortex method is devised to simulate the problem. The airfoil is modeled to include thickness and camber effects. The periodicity of a helicopter rotor over each revolution is also taken into account. The effect of the airfoil wake and its evolution due to the periodicity is studied. The equations for calculating airfoil loads are modified to satisfy conditions in a multiply connected domain, due to the presence of two airfoils. The interaction is parameterized with respect to the separation distances and angles of attack. An approximate aerodynamic interaction model is expected to be useful in understanding the vibrations, and easier to incorporate in an aeroelastic code.
Nonlinear Signal Processing Algorithm for Remote Acoustic Source Localization in a Shallow Ocean

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When locating remote acoustic sources in a shallow ocean sound channel, the established array signal processing technique known as matched field processing (MFP) has shown much success. However, MFP is sensitive to mismatch between the modeled and actual environments, and may fail to localize acoustic sources in the presence of such mismatch, particularly at high frequencies. A recent nonlinear array signal processing technique, frequency difference MFP (Abadi et. al. 2012, Worthmann, et. al., under review), has shown some success in localizing high frequency sources by moving the replica calculations to a lower, out-of-band, difference frequency where the detrimental effects of environmental mismatch are less severe. To extract the requisite out-of-band difference frequency information from the measured signals, a quadratic product, termed the autoprodut, is formed from complex signal amplitudes separated by the difference frequency but still lying within the signal bandwidth. Through the use of simple multipath propagation environments, the nature of this autoprodut is explored, and the reasons that it provides out-of-band field information are presented.
IOF: Industrial, Operations, and Financial Engineering
Macroscopic look at the Equity Markets

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The aim of this research is to investigate the existence of sensors to monitor Equity Markets. We look at the equity markets with a macroscopic viewpoint. This look enables us to extract significant information about the overall dynamics of the financial markets. In this view, we are able to view the market within the context of the physics principles of ‘mass and momentum conservation laws’ and with the variables ‘density’, ‘flux’, ‘pressure’, ‘average velocity’, etc. This then allows us to monitor some of these variables through sensors in the market. In the era of high frequency trading powerful tools are needed to monitor/control the equity markets. We propose a method that predicts and provides alerts in cases of odd activities. Our primarily analysis shows that our sensors are able to capture valuable information about the flash crash day, where it is known that the volatility was created by high frequency trading.
Scheduling Downloads Under Uncertainty During a Small Satellite Mission

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We extend prior work on the single satellite download scheduling problem (SMSP) by considering uncertainty in the availability of ground stations. We consider several strategies to handle the case were a download is scheduled but the ground station is unavailable: (1) do we still use data and energy and (2) can we change our original plan for future downloads. This leads to several stochastic optimization models, some reduce to a deterministic formulation while some lead to exponentially large scale problems. We propose a solution approach for each of them and run computational experiments to evaluate performances in run time and objective value. We use insight from these computational experiments to propose recommendations on small satellites design to improve performance during download operations under uncertainty.
Nonparametric Data-Driven Algorithms for Multi-Product Inventory Systems

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We propose a nonparametric data-driven algorithm called DDM for the management of stochastic multi-period multi-product inventory systems with a warehouse-capacity constraint. The demand distribution is not known a priori and the manager only has access to past sales data (often referred to as censored demand data). We measure performance of DDM through regret, the difference between the total expected cost of DDM and that of an oracle with access to the true demand distribution acting optimally. We characterize the rate of convergence guarantee of DDM. More specifically, we show that the average expected T-period cost incurred under DDM converges to the optimal cost at the rate of $O(1/\sqrt{T})$. Our asymptotic analysis significantly generalizes approaches used in Huh and Rusmevichientong (2009) for the uncapacitated single-product inventory systems. We also discuss several extensions and conduct numerical experiments to demonstrate the effectiveness of our proposed algorithm.
Dual Decomposition Algorithms for Solving Chance-Constrained Binary Programs

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We study a dual decomposition algorithm for chance constrained binary programs with a variety of industrial and financial applications. The approach assumes finite realizations (scenarios) of random parameters, and uses binary logic variables to activate/deactivate the probabilistically enforced constraints in individual scenarios. We resort to Lagrangian relaxation and assign multipliers to constraints that involve variables or parameters across scenarios. Because of the 0/1 nature of the logic variables, the dual problem has closed-form intermediate solutions, which can be utilized to avoid the big-M constants induced from a standard mixed-integer programming reformulation of a chance constraint. We apply subgradient methods to optimize the problem involving scenario-based subproblems that can be computed efficiently in parallel. The algorithm follows a two-sided objective bounding process that iteratively (i) solves scenario subproblems and recovers dual objective values as lower bounds, and (ii) explores subproblem solutions as feasible solutions to the original problem and updates upper bounds. We exploit strong inequalities that are particularly designed for “clipping” and “cropping” forbidden vertices, to remove explored solutions from future consideration. We demonstrate the efficacy of our approach by testing facility location problem instances with service-level constraints.
Simulating a Medical Observation Unit for Pediatric Emergency
Department

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The focus of this research is on evaluating the potential impact of adding an observation unit (OU)
at Mott Children’s Hospital Emergency Department (ED) at the University of Michigan to help
facilitate patient care (e.g. reduce patient waiting times, length of stay). Observation units (OUs)
provide an alternative disposition decision for ED patients who may benefit from further
observation, such as those who are not ill enough to be admitted, but not well enough to be
discharged. Patients can be placed in an OU for monitoring, diagnostic evaluation, and/or
treatment prior to disposition. Potential benefits of an OU include increasing the likelihood of a
correct disposition decision (i.e. admit vs. discharge) by providing medical providers additional
time to monitor the patient’s condition. In so doing, it may also help reduce readmissions into the
ED and admissions into an inpatient unit (IU) thereby “freeing up” ED and inpatient beds. Lastly,
simply adding beds to the ED can help reduce the delay to treatment for many ED patients, as
well as the number of patients who leave without being seen, especially when the ED is
congested.
Two-Stage Distributionally Robust Unit Commitment with Generalized Linear Decision Rules

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As the renewable energy takes a growing share of the electricity markets, a considerable number of new renewable generators (e.g., solar and wind farms) are incorporated into daily power system operations. Because of fluctuating weather conditions or a lack of complete historical data, it can be challenging to accurately estimate the joint probability distribution of the renewable energy. In this paper, based on a small amount of marginal historical data, we propose a two-stage distributionally robust unit commitment (DRUC) model to help us make good unit commitment (UC) decisions to accommodate the renewable energy integration which has intermittent and volatile nature. In this model, we use a set of plausible probability distributions to provide the information of the uncertain variables instead of just using an uncertainty set. Then we formulate a two-stage DRUC model that makes the UC decisions in the first-stage problem, and the dispatch decisions in the second-stage problem after the solar and wind power randomness is realized. Finally, we verify the effectiveness and superiority of our proposed model by comparing the obtained UC decisions with the perfect-information unit commitment decisions (PIUC) (i.e., the decisions obtained by knowing the actual solar or wind power realization beforehand) and the UC decisions obtained by the classical RUC model. This model is less conservative than classical robust unit commitment (RUC) models, and at meanwhile more computationally tractable by using the generalized linear decision rules.
Exact Methods for Finding Pareto-Dominant Resident Shift Schedules for a Pediatric Emergency Department

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Building resident shift schedules for the U-M Pediatric Emergency Department is a multi-objective combinatorial problem. Chiefs cannot provide a single objective function or weights to trade off metrics of patient safety, educational training requirements, and resident satisfaction. We have developed an algorithm for generating Pareto-dominant schedules to reduce the solution space for Chief Residents to review and to help elicit their preferences.
Scheduling Medical Residents With Conflicting Requests For Time-Off

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In scheduling medical residents, the objective function is often to maximize resident satisfaction across the space of feasible schedules, relative to the many hard constraints that ensure appropriate patient coverage, adequate training opportunities, etc. A common metric of resident satisfaction is the number of time-off requests that are granted. Simply maximizing this total, however, can be computationally challenging and may lead to sub-optimal schedules since some requests have higher priority than others. For example, it might be better to grant one resident's request for their family member's wedding in place of two residents' requests to attend a football game. Another approach is to assign a weight to each request and maximize the weighted sum of granted requests, but determining weights that accurately represent resident preferences can be quite challenging. We propose to instead identify the exhaustive collection of maximally feasible and minimally infeasible sets of requests which can in turn be used by the scheduler to select their preferred solution. Specifically, we have developed an algorithm, which we call Request Selection Via Pruning (RSVP), to identify these sets. We present this algorithm along with computational results based on a real-world problem of scheduling residents at the University of Michigan C.S. Mott Pediatric Emergency Department. Although we focus our exposition on the problem of resident scheduling, our approach is applicable to a broad class of scheduling problems with soft constraints.
Improving Patient Flow in an Outpatient Chemotherapy Infusion Center

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The flow through an outpatient chemotherapy infusion center contains elements of randomness at various points in the process. This can cause disruptions that lead to patient delays and overtime for the staff. We study the full process experienced by infusion patients in the University of Michigan Comprehensive Cancer Center, identify key bottlenecks within this process, and develop engineering-based techniques aimed at reducing patient delays and improving staff workload balance. Our methods include creating simulation models to help us understand how process flow changes will affect patient waiting times in the phlebotomy (blood draw) area. We also utilize optimization modeling to explore the tradeoff between potential time savings and costs for various drug mixing policies. Finally, we consider the use of templates and optimization techniques to improve patient appointment scheduling.
Innovations in Surgical Instrument Reprocessing Methods for Improved Patient Safety and Financial Stewardship at UMHS

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Efficiency in surgical instrument reprocessing is a critical challenge for many large hospital systems. Instruments that are insufficiently cleaned and therefore still contaminable are identified as having bioburden and can have a tremendously negative impact on patient safety and surgical outcomes. They have also further been identified as a causative agent for healthcare-acquired infections (HAIs), which result in annual financial losses of approximately $6.5 billion dollars in the U.S. Our study examines how i) instrument cleanability and ii) instrument-set configurations impact the effectiveness of surgical instrument reprocessing as well as the associated quality of care and costs of delivery. Using mathematical modeling and an innovative cleanability-rating tool developed in partnership with UMHS clinicians, we demonstrate how separating even one harder-to-clean instrument-type (Kerrison) from the Minor Neuro Set has the potential to yield a 40\% reduction in reprocessing costs due to bioburden. UMHS is currently piloting the reconfiguration of Minor Neuro into two different subsets and anticipates an overall reduction in bioburden incidents, which will significantly improve patient safety in addition to UMHS’s financial operating margins. Through our work we also highlight the framework’s potential to influence industry guidelines on surgical instrument design, and national policies on surgical instrument reprocessing.
Determining an Optimal Schedule for Pre-mixing Chemotherapy Drugs

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In collaboration with the University of Michigan Comprehensive Cancer Center, we have explored how the randomness at various steps in the process flow can cause disruptions leading to patient delays and overtime for infusion staff. A majority of previous efforts have focused on scheduling and quality improvement of chemotherapy infusion centers. However, one major opportunity to reduce patient delays is optimizing drug preparation at the pharmacy. We have developed a data-driven, optimization-based approach to improving the timeliness of drug preparation for chemotherapy infusion patients while reducing staff workload and improving resource utilization. We discuss results from static decision policies to determine the optimal schedule for pre-mixing chemotherapy drugs at the cancer center.
Optimal Double McCormick for Trilinear Monomials* Global Optimization of Non-convex Functions

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When using the standard McCormick inequalities iteratively to convexify trilinear monomials, as is common practice in modeling and software, there is a choice of which variables to group first. For the case in which the domain is a nonnegative box, we derive exact expressions for the volume of the resulting relaxation, as a function of the bounds defining the box. Volume seems to be a good measure in the context of nonlinear global optimization, corresponding to a uniform prior as to where an optimum may be located. In this manner, we characterize the optimal grouping and quantify the strength of the different possible relaxations defined by all three groupings, in addition to the trilinear hull itself.
Surface Defect Monitoring Using Robust Generalized Singular Value Decomposition

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The advent of advanced imaging technologies creates a unique opportunity of garnering a substantial amount of information about a process. Using image processing techniques, such as edge detection and decomposition methods, practitioners are able to extract some important features from the images in order to form a basis for process monitoring and defect detection. In practice, the images usually contain a certain amount of noise covering the signal in the image. The noise components in these images sometimes suggest spatial or spatiotemporal correlation that if neglected, the performance of existing methodologies is affected. Furthermore, under some environmental conditions, like high temperature the images taken from the process might be abnormal in the sense of unclear visibility or excessive amount of noise. The existence of such outliers affects the performance of current techniques in extracting the critical features used for process monitoring. In this paper, a robust generalized singular value decomposition (RGSVD) is proposed to extract the features of the images when the noise components are correlated and some of the images are contaminated. The extracted features, then, can be used for monitoring a process in order to detect the defects on the images. The performance of the proposed RGSVD method is evaluated using a simulation study. Besides, the RGSVD method is applied to a real dataset in rolling-bar process for detecting the defects on the rolling bars.
Data-driven Optimization Approaches for Optimal Power Flow with Uncertain Reserves

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Aggregations of electric loads, like heating and cooling systems, can be controlled to help the power grid balance supply and demand, but the amount of balancing reserves available from these distributed resources is uncertain. In this paper, we investigate data-driven optimization methods that are suited to dispatching power systems with uncertain balancing reserves provided by load control. Specifically, we formulate a chance-constrained optimal power flow (OPF) problem in which we aim to satisfy constraints that include stochastic variables jointly with a specified probability or individually with different probability guarantees. We focus on the realistic case where we do not have full knowledge of uncertainty distributions and compare the performance of distribution-free approaches with other stochastic optimization methods. We run experimental studies on the IEEE 9-bus test system assuming uncertainty in load, load control reserve capacities, and renewable energy generation. The results show the computational efficacy of the distributionally robust approach and its flexibility in trading off between cost and robustness of OPF solutions driven by the amount of data describing the uncertainty.
IVM: Integrated Circuits, VLSI and Microsystems
Whole Angle Mode Micro-machined Fused-Silica Birdbath Resonator Gyroscope

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We present the fused-silica micromachined birdbath resonator gyroscope (µ-BRG) operating in the whole angle (WA) mode. The key advantages of whole angle mode operation are direct angle measurement, large bandwidth, and large full-scale range which is needed in detecting the motion of fast-moving objects. The µ-BRG is made with fused silica using a micro blow-torching process and has n=2 wineglass modes at 10.46 kHz with a small frequency mismatch (Δf = 10 Hz) and a decay time (τ) of 2.2 seconds. Gyroscope vibrations are detected using a trans-impedance amplifier, and IQ demodulated using a Zurich Instruments HF2LI lock-in amplifier. Linear feedback control is applied to the gyroscope in order to sustain constant amplitude vibrations and reduce quadrature coupling between the two wineglass modes. Lastly, we estimate the angular displacement of the controlled gyroscope using software. The WA-BRG achieves a stable angular gain \( A_g = 0.27 \), 700°/s full-scale range, and a bias stability of 1°/hr.
Phase Change Optical Shutter with Subwavelength Metallic Line Array

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This paper introduces a new electro-optical shutter using the Germanium Telluride (GeTe) within an array of gold nano lines for the light at the wavelength of 1550nm. Such a modulator is needed in most of the systems such as optical commination, printers, spectroscopy, etc. The GeTe is a phase change material and needs to be cooled in longer than 2µs to get crystalized. However it needs to be cooled very rapidly in less than 500ns for amorphization. The gold lines are responsible to heat up the structure up to crystallization temperature which is about 300°C for crystallization and 700°C for amorphization. The change of the refractive index by crystallographic change in GeTe results in modulation of the TM polarized light that is passing through the metallic array. This results in less than 2dB loss when the GeTe is amorphous and more than 14dB isolation when it's crystalline. The array of gold line has a sub-wavelength thickness and period in order to let the light to pass at 1550nm. The gold lines’ array are fabricated in Lurie Nano-fabrication facility using the E-Beam lithography on top of the borosilicate glass wafer (Borofloat 33®). Then the GeTe film is sputtered on top of the gold lines from a target using the Lab-18 sputterer. The experimental transmission of the modulator in both crystalline and amorphous phases is measured using FTIR spectroscopy (PerkinElmer Inc.). It shows more than 74 % transmission in “on” state and less than 4% transmission in the “off” state.
All-digital phase-locked loops (ADPLLs) are preferred for frequency generation over traditional analog PLLs to take advantage of process scaling. ADPLL architectures offer area savings by eliminating large loop filters, reconfigurability of the loop gain and bandwidth, and are mostly portable across processes. Previous work has demonstrated that integer-N ADPLLs can be implemented using digital synthesis and automatic place-and-rout (APR) tools, resulting in a simplified and easily customizable design flow. However, despite the substantial work that has been achieved in automating the layout of digitally controlled oscillators for these ADPLLs, a large amount of the design still relies on highly iterative procedures. Digitally controlled oscillators (DCOs) are designed and redesigned at the cell and architecture level several times in order to achieve the desired specs, before the automated layout process becomes useful. Much of this is due to uncertainty about the effect of various architectural knobs on tuning range, power, and phase noise. To address this issue, we have designed, fabricated, and tested a test chip containing synthesized oscillators in a number of configurations. Additionally, we have produced a chip with a 300MHz – 3.0GHz ADPLL clock generator leveraging a phase domain based architecture, which is targeted at process core clocking applications. Architecture and preliminary simulation results are shown.
Temperature Compensated Fused Silica Resonators Using Embedded Nickel-Refilled Trenches

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This paper reports a new fabrication process that utilizes nickel-refilled trenches to achieve passive temperature compensation in fused silica. These nickel-refilled trenches are embedded into the body of the resonator using a novel trench refill method that embeds the nickel under the piezoelectric layer. Using this scheme, piezoelectrically actuated fused silica resonators are demonstrated with a temperature coefficient of frequency (TCF) of +50.28 ppm/K (reduced from +77.65 ppm/K) and quality factors of over 5,000. Additionally, a higher frequency mode at 16 MHz shows a TCF of +21.84 ppm/K (reduced from +71.94 ppm/K). This compensation method can be extended to simultaneously actuate a compensated and an uncompensated mode of the same device, allowing for both temperature measurement and stable operation in the same device volume. This opens up applications for temperature-stable dual-mode ovenized frequency references in a very small device area. This is the first time that passive temperature compensation has been shown for fused silica micro-mechanical resonators.
Modular Stacked Variable-Compression Ratio Multi-Stage Gas Micropump

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Gas micropumps are a crucial component of many emerging devices such as handheld environmental and health monitoring systems, breath analyzers, gas sensors, mass spectrometers, gas chromatography (μGC) systems, and some other Lab-on-Chip (LOC) devices. In all these applications the size, weight, power consumption and pumping performance, such as pressure difference and flow rate, are critical.

We report the design, fabrication and testing of a new “stacked” multi-stage electrostatic gas micropump. Utilizing a stacked structure provides modularity as well as the ability to change the number of pumping stages post-fabrication to achieve the required pressure for a given application. The stacked design also eliminates the need for bidirectional movement of the pumping membrane. The new design presents a novel method to adjust the volume ratio of a given stage to achieve a uniform pressure increase across individual stages of the multi-stage system. A pressure difference of 2.5 kPa and air flow rate of 860 μL/min is obtained by a 3-stage stacked micropump. An individual micropump stage is 5.5×4×0.5 mm³ and each pumping/microvalve membrane is 2 × 2 mm².
AC Electroosmosis coupled LSPR nanobiosensor for ultra-low concentration biomarkers detection

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Recent therapeutics development leads to an urgent need of rapid, accurate biosensing platform that can identify ultralow concentration of biomolecules for monitoring human’s immune status and early disease detection. With the benefits of sensor miniaturization, multiplexing capacity, low sample volume, high sensitivity and throughput, LSPR-based (Localized surface plasmon resonance) biosensing platforms are considered to be the next generation of plasmonic sensing systems. In this paper, a novel label-free LSPR-based nanoplasmonic microfluidic sensor coupled with electrokinetic micromixer is proposed. By applying an AC voltage to the microelectrodes deposited on sensor substrates, the induced AC electroosmosis flow motion works as a mixer to push the analytes down to the sensing surface. The approach(1) increase the limit of detection (2) reduce the sample volume (3) shorten the assay time (4) reduce the non-specific binding, all to the unprecedented level. Our preliminary data shows the sensor can measure biomarkers (biotin-streptavidin) down to several femtomolar ($10^{-15}$ mol/L) level with assay time less than 15 min, which is the most sensitive published label-free plasmonic biosensor to the best of our knowledge. Such a high sensitivity will broaden this technology to the development of non-invasive biomarkers detection in saliva rather than conventional patient's serum. Meanwhile, the wide variety choice of receptor and analytes also enable this technology to be applied in broad research areas such as protein expression profiling, gene expression analysis, molecular-level analysis of infectious diseases, and human leukocyte antigen (HLA) testing.
3-D Biomimetic Sensor Arrays

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This project focuses on the design, simulation and fabrication of highly-dense arrays of 3-D high aspect-ratio MEMS structures that can imitate biological hairs. Hair has many unique properties including high aspect ratios, local neural processing, robustness, and multiplicity of functions. A key feature of our arrays is the tall, 3-D structure which allows for spatially efficient integration of traditional MEMS resonators which use a large mass to bend a much smaller spring. The sensors can be combined in series or in parallel and can include local signal processing using underlying CMOS circuitry. Here we implement 2-axis capacitive acceleration sensor arrays. Each sensor consists of a proof mass atop a narrow post. The post acts as mechanical spring and the mass is surrounded by four silicon electrodes for capacitive sensing of deflection. The sensor is fabricated using a silicon-silicon wafer-level integrating microfabrication process. DRIE is used to define the small capacitive gaps while simultaneously etching more deeply to separate neighboring sensors. The device is modeled in COMSOL to maximize sensitivity within the available process windows. After DRIE the wafer is bonded to another silicon wafer which has been prepared with recesses and metal electrodes and routings. By taking advantage of high aspect-ratio DRIE, we have fabricated a new class of dense 3-D high sensitivity MEMS accelerometer arrays which offer improvements in performance and robustness, and can potentially provide multi-sensor functionality.
Development of RF Ohmic Switches Using GeTe Phase Change Material

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Phase Change (PC) materials refer to a class of chalcogenide compounds including germanium antimony telluride (GST) and germanium telluride (GeTe), which have the phase transition properties, showing greatly different resistivity at two states. The state transition between the amorphous (OFF) and crystalline (ON) states is achieved by thermal actuation, and the resistivity is different by several orders of magnitude. In our project, GeTe is chosen as the phase change material used for RF switching applications due to its low crystalline resistivity and high OFF/ON resistance ratio. We have come up with RF ohmic switch designs using GeTe with direct heating and indirect heating schemes. An insertion loss of less than 0.2 dB and isolation above 11 dB up to 20 GHz is achieved. A comprehensive non-linearity thermoelectric modeling of the phase change switches has recently been developed further investigate the limiting factors of the power handling capability and enhance the performance. Future work of RF phase change switches will focus on improving the insertion loss and isolation, power handling and switch reliability.
MDM: Multidisciplinary Design, Manufacturing, and Mechatronics
Aerostructural design optimization of an adaptive compliant trailing edge on an aircraft wing for improved fuel efficiency

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Many factors play a role in aircraft design. One of the leading factors in modern design of commercial transport aircraft is fuel efficiency. Decades of experience and design improvements on the conventional tube and wing configuration has led to nearly optimal designs, which offer little potential for further fuel efficiency improvements. As such, many current research efforts are focused on gaining knowledge and experience with new technologies and configurations, such as the blended wing body, truss braced wing, and morphing trailing edges, which offer improved efficiency. In this work, we quantify the additional efficiency benefits offered by adaptive compliant trailing edge technology.

To measure the benefits of morphing trailing edges, a series of gradient based, high-fidelity aerostructural optimizations is compared. The optimizations are started from the undeformed Common Research Model (uCRM), a benchmark geometry used by a number of design researchers. The structural member thicknesses and shape/twist of the wing’s outer mold line are optimized for minimum fuel burn. Additional shape design variables are then added to model the effects of the morphing trailing edge. These morphing shape design variables are independently optimized for a variety of flight conditions, yielding the optimal morphed shape and minimum fuel burn at each condition. These optimal shapes are then aggregated to form a performance surrogate, which is used to calculate fuel burn over an entire mission. The aircraft with the morphing trailing edge burned about 5% less fuel than its conventional counterpart, showing that this technology offers substantial fuel efficiency improvements.
Fabrication Encoded Piezoresistive Properties in Thin Film Polymer Composites

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The design of material properties in polymer composite films presents considerable promise for applications in structural health monitoring. The need for improved structural performance characterization is apparent as multiple challenges pose economic and safety threats to American’s infrastructure. Primary to these challenges are the ageing of civil infrastructure and use of novel materials in mechanical and aerospace systems. The performance of many structural systems can be determined through detailed sensing over a limited area on system-critical structural components. Thin film sensors can be utilized for distributed sensing over such critical areas. One compelling class of sensing materials for such systems is carbon nanotube-polymer composites fabricated through a layer-by-layer deposition process with properties that can be encoded through material selection and processing parameters. Here we design and fabricate patterned polymer nanocomposite films through both dimensional and process controls. Film thickness, width, length, and annealing processes are systematically varied to display their influence on films properties. The impedance properties of these films as are characterized. The resistive response of films to strain is investigated through testing of films in uniaxial tension. Mechanical-electrical response and design capabilities are discussed along with explanations of possible mechanisms underlying observed behavior. Notably, the design and control of both positive and negative gauge factors in films comprised of the same building blocks are displayed.
2D Material Based Field-Effect Transistor Arrays Fabricated Via Nanoimprint-Assisted Shear Exfoliation (NASE)

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As the most widely studied transition metal dichalcogenides (TMDC), MoS₂ recently emerged as an attractive material candidate for making novel functional devices due to its excellent electronic, photonic, and mechanical properties. However, for industrial scale-up applications, the research community currently needs upscalable processes for producing large-arrays of high-quality, highly-uniform MoS₂ device structures. In addition, although many research efforts have been focused on exploring attractive properties associated with MoS₂ monolayers, few-layer MoS₂ structures are indeed demanded by many practical device applications, because of their sizable electronic/photonic state densities for driving upscalable electrical/optical signals. In this work, we present a new approach, termed as Nanoimprint-Assisted Shear Exfoliation (NASE), which uniquely combine the nanoimprint lithography and shear exfoliation to generate multilayer MoS₂ and other TMDC structures with a high uniformity of thicknesses as well as electronic properties over centimeter scale. Using this approach, we demonstrate MoS₂ based field effect transistors and multiple FET based bio-sensors. Our biosensors show a high degree of device-to-device consistency in sensor responses behavior to specific biomarkers.
Low Cost and Energy Efficient Vibration Reduction of Ultra-precision Manufacturing Machine

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This research investigates the problem of optimally locating passive vibration isolators to minimize residual vibration caused by exogenous disturbance forces. The stiffness and damping properties of the isolators are assumed to be known and the task is to determine the isolator locations, which are nonlinearly related to system states. This research proposes an approach for reformulating the nonlinear isolator placement problem as a LTI control problem by linking the control forces to measured outputs using a feedforward term. Accordingly, the isolator locations show up as a static output feedback gain matrix which is optimized for residual vibration reduction using standard $H_\infty$ optimal control methods. Simulations and experiments on SISO and MIMO case studies are used to demonstrate the merits of the proposed approach. Even though presented in the specific context of ultra-precision manufacturing machines, the proposed method is applicable to the optimal design of other passive systems with nonlinear relationships between design variables and system states.
Active Assist Device for Precision Scanning Stages

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A novel magnet assisted stage concept that simultaneously reduces the heat and vibration of precision scanning stages, due to the high accelerations and decelerations (acc/dec) of moving parts, is presented. The novel stage concept utilizes repelling permanent magnets (PMs) to store/release the mechanical energy of the scan table into/from the magnetic field during acc dcc to reduce the motor heating, while the reaction assist force is conducted outward to the ground to reduce the vibrations of isolated base. This presentation highlights an optimal control approach, which exploits a basis spline based trajectory for actuators, to configure a pair of repelling PMs as an active assist device (AAD). The superior performance of the AADs in reducing heat and vibration is experimentally demonstrated using two practical case studies related to silicon wafer scanning, in which cases the reference trajectories have varying scan strokes/positions. Compared to the passive assist device (PAD) configuration, in which case the position of PMs is fixed, over 77% and 52% reductions in heat and vibration, respectively, are achieved.
Grinding Wheel Dynamics and Plaque Removal Mechanism in Atherectomy

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Atherectomy is a catheter-based minimally invasive procedure to modify the plaque within atherosclerotic arteries using a diamond abrasive grinding wheel. This study was designed to investigate the grinding wheel motion and its corresponding contact force with the vessel. To this end a transparent arterial tissue-mimicking phantom made of polyvinyl chloride was developed, a high-speed camera and image processing technique were utilized to visualize and quantitatively analyze the wheel motion in the vessel phantom, and a piezoelectric dynamometer measured the grinding forces on the phantom during the procedure. Observed under typical atherectomy rotational speeds of 60,000, 90,000, and 120,000 rpm in a 4.8 mm caliber vessel phantom, the grinding wheel motion was a combination of high-frequency rotation at 1,000, 1,500, and 1,660.4-1,866.1 Hz and low-frequency orbiting at 18, 38, and 40 Hz, respectively. The measured forces were also composed of these high and low frequencies, matching well with the rotation of the grinding wheel and the associated orbital motion. The average peak force ranged from 0.1 to 0.4 N at different rotational speeds. The presented approach took the lead in investigating the plaque removal mechanism in atherectomy, which is important for device development and surgical planning.
MSE: Materials Science and Engineering
Short Crack Growth and Very High Cycle Fatigue Behavior of Magnesium Alloy WE43

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Despite their potential, magnesium alloys are currently underdeveloped with critical mechanisms in magnesium not yet fully understood. In this study, the short crack growth and very high cycle fatigue behaviors of the hot-rolled rare-earth magnesium alloy WE43 were investigated using displacement-controlled ultrasonic fatigue (USF) instrumentation and a novel combination of USF and scanning electron microscopy, termed UFSEM. The roles of grain size and precipitate structure on fatigue life and crack propagation behavior in the T5, underaged and T6 conditions were investigated. The effect of grain boundary misorientation on short crack propagation was studied in the large-grained underaged and T6 conditions using basal-oriented notches, and was observed to play a significant role in crack growth retardation at grain boundaries. UFSEM was used to characterize micro-scale fatigue damage mechanisms. Mapping of fracture facets revealed crack growth behavior that varied significantly from surface-measured growth behavior.
Influence of hot isostatic pressing on the microstructure and tensile behavior of HPDC Mg AM50 alloys

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The mechanical properties of high pressure die cast (HPDC) magnesium can be highly variable and dependent on the manufacturing process history and on location within a casting. This investigation provides experimental input to modeling activities for the development of an ICME capability, to assess and quantify the impact of section thickness on the microstructure and tensile behavior of HPDC Mg AM50 alloy. AM50 2.5 mm thick plates were super vacuum die cast and characterized via quantitative metallography and uniaxial tensile testing. Plates were processed by hot isostatic pressing (HIP) to identify the effect of different microstructural features, specifically β-Mg17Al12 and shrinkage porosity, on the mechanical behavior. This allows investigation specifically on the effects of casting defects, such as oxide bifilms on the microstructure and tensile behavior of these plates.
Nanoscale Orientation Effects on Carrier Transport in a Low-Band-Gap Polymer

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We show that the out-of-plane hole mobility of the low-band-gap polymer poly[4,8-bis-(2-ethylhexyloxy)-benzo[1,2-b:4,5-b’]dithiophene-2,6-diyl-alt-4-(2-ethylhexyloxy-1-one)thieno-[3,4-b]thiophene-2,6-diyl] (PBDTTT-C) is film thickness dependent: it was nearly an order of magnitude faster in films in the thickness range $h > 500$ nm, compared to films of thickness $h \sim 100$ nm. This behavior is associated with the morphology. Due to a geometric confinement and to polymer/substrate interactions, the average orientation of the chains in the thinnest films was predominantly parallel to the substrate. In this thickness range, the out-of-plane hole mobilities $\mu$ were necessarily low and $\beta$, a measure of the strength of the field dependence of the mobility, was largest. Within the framework of the Gaussian Disorder model, the relative value of $\beta$ suggests that the largest effect of positional disorder on the carrier transport was most significant in the thinnest films. The hole mobility $\mu$ increased and depended less on the electric field ($\beta$ decreases in magnitude) with increasing thickness, due evidently to the increased degree of orientation of the domains with respect to the direction of the field (normal to the interfaces). These findings demonstrated the profound impact of the substrate on the morphology and of the morphology on the charge carrier mobility.
Biorealistic Implementation of Synaptic Behaviors Using Metal Oxide Memristors with Second Order Effects

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Memristor, a two terminal nanoscale electrical device whose conductance could change according to historical stimulation applied, has attracted broad interest as a promising candidate for future memory and computing applications. Particularly, it is believed that memristors can effectively implement synaptic functions and enable efficient neuromorphic systems. Most previous studies, however, focus on implementing specific synaptic learning rules by carefully engineering external programming parameters instead of focusing on emulating the internal cause that leads to the apparent learning rules. Here, it is shown that by taking advantage of the different time scales of internal oxygen vacancy (VO) dynamics, including mobility variation and heat transient, in two types of metal oxide-based memristor including tungsten oxide memristor and tantalum oxide memristor, diverse synaptic functions at different time scales such as paired pulse facilitation, spike-timing dependent plasticity and activities dependent plasticity, can be implemented naturally. Mathematically, the device can be effectively modeled as a second-order memristor with a simple set of equations including multiple state variables. Not only is this approach more biorealistic and easier to implement, by focusing on the fundamental driving mechanisms it allows the development of complete theoretical and experimental frameworks for biologically inspired computing systems.
Thermal stress analysis of photovoltaic modules using thermo-elastic modeling

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At a time when solar cells are still a substantial investment, it is important that they have a durable lifetime and that their functionality is preserved. Thermal stresses have a significant impact on solar cell reliability and can lead to fracture or fatigue. The prevailing method for quantifying thermal stresses is finite-element-analysis although this can often be an expensive and time-consuming approach. In this study, thermo-elastic modeling was investigated as a simple and quick alternative for quantifying thermal stresses in PV modules. The BP350 was selected as a commercial PV module for the study and ambient temperature data from Riyadh was used for the thermal model. Computations were performed on MATLAB and the results were then verified with a finite-element-analysis on Abaqus. The results from both models are congruent and demonstrate that the simplifications made with the thermo-elastic model have minimal effect on the accuracy of the results.
A parallel 3D multiscale crystal plasticity finite element (CPFE) code has been developed as part of the integrated suite of validated computational tools for the DOE Software Innovation Center for Integrated Multi-Scale Modeling of Structural Metals. Using experimental microstructure images as input, the code can be used to compute the response of crystalline aggregates to mechanical loading – in the form of grain-level stress/strain contours and pole figures. The single crystal response in this code is based on evolution laws for micro-scale state variables, namely, slip and twin system resistances. The current work is focused on validating the CPFE model by comparing with strain maps obtained from micro-scale digital image correlation. The strain maps will serve to refine models for various hardening mechanisms in the Mg alloy (WE43) including interactions between crystallographic slip and twinning mechanisms. In addition, DIC tests indicate significant grain boundary cracking in the microstructure. The data will guide the development of cohesive laws for Mg grain boundaries.
Catalyst migration in conjugated polymer synthesis

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Conjugated polymers’ propitious combination of mechanical flexibility along with light absorption/emission and charge conductivity has stimulated research into applications such as transistors, light emitting diodes, and solar cells. The discovery of living, chain-growth methods to polymerize conjugated monomers has enabled researchers to tune polymer properties by manipulating molecular weight, end-groups, and copolymer sequence. The unique feature of this living polymerization is a metal-polymer pi-complex, which confines the catalyst to a single polymer chain throughout the polymerization. However, several reports have demonstrated that this catalyst complex is not restricted to the chain-end and that the catalyst can migrate along the polymer chain to react at either end. Migration between active chain-ends limits the ability to dictate polymer sequence and end-groups, both of which play important roles in solid-state organization and electronic properties. We developed a model system to investigate under what conditions catalyst migration occurs by reacting one or both polymer ends with a capping agent. While Ni and Pd catalysts yield similar results in polymerizations, migration products were only observed with Pd catalysts. This greater propensity for Pd catalyst migration along the polymer pi-system limits our ability to define sequence in copolymerizations. However, we are exploiting this migration to expand the limited monomer scope of Ni to access a broader range of solid-state and electronic properties.
Designing Durable Icephobic Surfaces

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Ice accretion negatively impacts critical infrastructure, as well as a range of commercial and residential activities. Icephobic surfaces are defined by an ice adhesion strength $\tau_{\text{ice}} < 100$ kPa. However, the passive removal of ice requires much lower values of $\tau_{\text{ice}}$, such as on airplane wings or power lines ($\tau_{\text{ice}} < 20$ kPa). Such low $\tau_{\text{ice}}$ values are scarcely reported, and robust coatings that maintain these low values have not been reported previously. Here we show that, irrespective of material chemistry, by tailoring the crosslink density of different elastomeric coatings, and by enabling interfacial slippage, it is possible to systematically design coatings with extremely low ice-adhesion ($\tau_{\text{ice}} < 0.2$ kPa). These newfound mechanisms allow for the rational design of icephobic coatings with virtually any desired ice adhesion strength. By utilizing these mechanisms, we fabricate extremely durable coatings that maintain $\tau_{\text{ice}} < 10$ kPa after severe mechanical abrasion, acid/base exposure, 100 icing/de-icing cycles, thermal cycling, accelerated corrosion, and exposure to Michigan wintery conditions over several months.
The origin of unique optical properties of gold nanorods such as distinctive extinction bands in the upper visible or near-infrared region is surface plasmon (SP) oscillation of free electrons. To understand how these collective electrons interact with optical waves, we should be aware of their electrostatic properties. By implementing various high resolution electron microscopic techniques, we visualized spatial electrostatic potential of single AuNR. AuNR has anisotropic charge accumulation on their surface, which can be defined as a polarized surface charge density. We believe that this anisotropic potential of AuNR is derived by non-uniformly distributed surfactants on its surface, which also has been successfully visualized. Computation of electrostatic potential of gold nanorod considering this charge distribution from surfactant is well matched with the experimental result. More importantly, we demonstrate that this asymmetry of potential in AuNR could be one of the origins of nonlinear optical response of AuNR. Although there are existing theories such as retardation effect, defects, and local environment, this finding could let us another approach to understand nonlinear optical response of various centrosymmetric metal nanoparticles.
Glycocalyx-mimetic Interfaces with Tunable Surface Charge: Electrokinetic investigations and Adsorption Kinetics

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A crucial component of our cells' immune machinery is the glycocalyx, a membranous structure composed of glycoproteins and carbohydrate residues that sheaths the cell and protects it from pathogen invasions. In this work, we present a model surface that recapitulates two key features of the sieve-like glycocalyx - the ability to resist non-specific adsorption as well as the capacity to specifically bind to target species through electrostatically mediated interactions. Bearing a strong negative charge, the glycocalyx can use blood circulation-induced streaming current to direct information exchange between the cell and its environment. Electrokinetic characterization of our model surfaces is therefore essential to understand their interfacial behavior. Streaming current measurements established that copolymers can be engineered to carry a tunable surface charge profile that is intermediate between that of its constituent monomers - a positively charged affinity site and initiation sites for polymerization of a glycopolymer brush whose chemical composition is glycocalyx-mimetic. To simulate pathogen binding to our surfaces, we used carboxylated polystyrene nanoparticles as proxy viruses. We understood adsorption behaviour through a combination of two methods: equilibrium adsorption was observed using fluorescence microscopy whereas adsorption kinetics were visualized by real time streaming current measurements. Our experimental results in conjunction with insights from our theoretical models demonstrate that pathogen interactions with our model surface can be tailored by pH, electrolyte environment, surface concentration of affinity sites, brush thickness and composition. Our results can be used to guide the design of biosensors and of coating-based models for studying the onset of infectious diseases.
Cross polarization for improved digital image correlation surface deformation measurements

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Digital image correlation (DIC) is a surface deformation measurement technique for which accuracy and resolution are sensitive to image quality. This work presents cross polarization, the use of orthogonal linear polarizers on light source(s) and camera(s), as an effective method for improving optical DIC measurements. The benefits of cross polarization are characterized through quantitative and statistical comparisons from two experiments: rigid body translation of a flat sample and uniaxial tension of a superelastic shape-memory alloy (SMA). In both experiments, cross polarization eliminated saturated pixels that degrade DIC measurements, and increased image contrast, which enabled higher spatial resolution by using smaller subsets. Subset sizes are usually optimized for correlation confidence interval (typically with subsets of 21 x 21 px or larger), but can be decreased to achieve the highest possible spatial resolution at the expense of increased correlation confidence intervals. Smaller subset sizes (such as 9 x 9 px) require better images to maintain correlation within error thresholds. We show that for 9 x 9 px subsets, the loss of valid DIC data points was reduced almost ten-fold with cross polarization. The only disadvantage we see to cross polarization is the decrease in specimen illumination due to transmission losses through the polarizers, which can easily be accommodated with sufficiently intense light sources. With the installation of relatively inexpensive linear polarizing filters, an optimum optical DIC setup can provide even better DIC measurements by delivering images without saturated pixels and with higher contrast for increased DIC measurement resolution.
Layer-by-Layer films on Spiky Hedgehog particles

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Layer-by-layer assembly (LbL) allows for the production of functional thin films that can be engineered for various applications including catalysis, and biomedicine. It currently is limited to primarily macroscopically flat surfaces such as a glass slide, and has recently been applied to spherical colloidal particles. By expanding layer-by-layer films to nanoscale features of microparticles, the diversity of layer-by-layer structures can be greatly increased. In this study, LbL was used on a complex spiky colloidal substrate—Hedgehog Particles (HPs). HPs consist of a polystyrene core surrounded by zinc oxide spikes. The surface corrugation from the spikes leads to reduced aggregation and colloidal stability, resulting in the ability to disperse particles in both organic and aqueous solvents. This unique property in addition to the high surface area of the HPs leads to numerous applications such as catalysis. LbL films can achieve uniform coating of nanocatalysts and other functional materials. Electron and confocal microscopy demonstrated uniform polymer LbL films on HPs. Furthermore, zeta potential measurements confirmed deposition of alternating charged polymer layers. Additionally, the cross-linking of polymer layers allowed for control of film morphology. These polymer films are currently being expanded to nanoparticle systems including gold nanoparticles and CdTe nanoparticles, leading to new applications in plasmonics and catalysis.
Recrystallization, Grain-growth, and Low-cycle Fatigue Behavior of Magnesium

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Grain size has a significant influence on mechanical properties of magnesium alloys and thus recrystallization and grain growth are important microstructural evolution processes in these materials. Static recrystallization has been investigated using Electron Back-Scatter Diffraction (EBSD) in pure Mg and the Mg alloy, WE43. Pure Mg was received in the form of extruded rod and WE43 was obtained in the form of hot-rolled plate. Static recrystallization, grain growth and texture evolution have been investigated on cylinders uniaxially compressed at room temperature and annealed at 200 to 525°C for 1-600 minutes. The level of dynamic recrystallization in the as-received condition was also characterized in these materials. The influence of alloying on static recrystallization and grain growth have been quantified and will be discussed in this presentation.
Surface X-Ray Diffraction Studies on ZnSnN$_2$ Thin Films

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Zinc Tin Nitride (ZnSnN$_2$) is a member of the ternary class of II-IV-V$_2$ semiconducting materials that have gained significant research interest in the recent past as a cheaper, earth abundant and environmentally friendly alternative to Indium-based materials used in photovoltaic and solid state lighting applications. Surface x-ray diffraction measurements performed at the Advanced Photon Source, Argonne National Laboratory on single crystal thin films of ZnSnN$_2$ grown on (111)-yttria stabilized zirconia (YSZ) substrates show the presence of a wurtzite structure contrary to theoretical studies that have predicted a stable orthorhombic structure at room temperature. Our recent x-ray measurements show the presence of an orthorhombic phase in thinner films grown by molecular beam epitaxy under low values of nitrogen flux and high substrate temperatures. We are currently studying the morphology of ZnSnN$_2$ thin films using 3-dimensional pole figure measurements and unit cell refinement calculations from x ray diffraction in order to characterize this orthorhombic phase. These findings suggest that a stable orthorhombic phase can be achieved in ZnSnN$_2$ thin films using epitaxy.
Circulating tumor cells (CTCs) are low frequency (1-10 cells/ml) tumor cells that are shed into the bloodstream and result in metastasis. Nonetheless, they provide easy and non-invasive access to tumor cells and represent the heterogeneous nature of tumor and hence act as potential surrogates of tumor cells for functional and genomic analysis. Here, we present a microfluidic device based on tunable polymer-graphene oxide (GO) nanocomposite film made through simple drop-casting on a patterned and surface modified glass substrate. The thermo-responsive polymer provides the thermally controlled capture/release functionality and also acts as matrix for GO sheets which in turn act as scaffolds for the cell capturing antibody, EpCAM. The PDMS encapsulation of the polymer-GO platform yields a microfluidic device for easy handling of blood.

To test device operation, fluorescently labeled MCF-7 cells (1000 cells/ml) were spiked into buffer and flowed at different flow rates (1-10ml/h). An average capture efficiency of >82% was achieved in the range of 1-3mL/h flow rate. Cell release experiments showed that on average >90% of the captured cells were released upon flowing cold PBS buffer. Over 90% of the released cells remained viable. Furthermore, the fabricated devices were used to study clinical samples from 10 breast and 3 pancreatic cancer patients. CTCs were isolated from eight breast and two pancreatic cancer patient samples in the range of 2-20 CTCs/ml. Additionally, to demonstrate the potential for single cell genomic analysis of released CTCs, fluorescence in situ hybridization (FISH) was conducted, revealing HER2 amplification in one breast cancer patient.
Paper Art Inspired Tunable & Multifunctional Composites

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Current research efforts in combining elasticity and multifunctionality have focused primarily on the atomic, molecular, and nanoscale structural elements of these materials. Drawing inspiration from paper art, we present a new framework to engineer composites in which the third dimension is coupled to functionality. Here we look into controlling defects, borrowing concepts from kirigami, a Japanese paper cutting technique. We carry out a systematic study of the mechanical response of assembled nanocomposite sheets patterned with periodic arrays of cuts guiding stress concentration and distribution. We show that finite element analysis can predict the mechanism underlying this strain response and show that stress is delocalized around the cut defects, where unpredictable local failure is prevented and ultimate strain increased to >300%. We show that kirigami can enable the fabrication of highly elastic composites that remain conductive at high strains. Finally, we establish a systematic framework to predictively control mechanical properties by design.
Wettability Based Patterning of Ovarian Cancer Cells on Paper

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The harvesting of groups of cancer cells or even individual cancer cells within a single population has been of particular interest for determining the subtle heterogeneities that can shed light on how cancer cells behave as they develop. This work demonstrates the isolation of groups of ovarian cancer cells (OvCar3) through the patterning of omniphilic domains on a piece of omniphobic filter paper. First, the filter paper is O₂ plasma etched and then silanized with (heptadecafluoro-1,1,2,2-tetrahyrdodecyl)triethoxysilane (F17-(EtOx)₃) to achieve omniphobicity. Next, the omniphilic regions are patterned onto the paper via O₂ plasma treating through a steel mask; in this study two types of patterns were utilized, squares and stripes. The OvCar3 cells are then cultured onto the entirety of the patterned paper and are given ten hours to settle and attach to the omniphilic regions. Within ten hours, cells are fully adhered only to the omniphilic regions with a negligible amount of cells attached to the omniphobic regions. This novel surface fabrication method allows for the facile capture of several cells on paper for further biological testing.
Predicting the Separation of CO$_2$/He, CO$_2$/CH$_4$, and CO$_2$/N$_2$ Mixtures in an Elastic Layered Metal-Organic Framework

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Elastic layered metal-organic framework (ELM) adsorbents are a group of latent porous crystalline materials that undergo abrupt reversible transitions from a nonporous collapsed structure to an expanded porous structure, termed a “gating” transition, through cooperative adsorption of guest molecules between layer planes. These materials have attracted interest due to their unique gating adsorption and high selectivity for simple gas molecules like CO$_2$ and show promise as a new generation of gas separators.

In this study, the Osmotic Framework Adsorbed Solution Theory (OFAST) is applied in the context of CO$_2$–gas mixture separations using the elastic layered metal organic framework ELM-11, [Cu(BF$_4$)$_2$(bpy)$_2$] (bpy = 4,4’-bipyridine), to generate predictions of ELM-11’s gating transition and capture performance as a function of pressure, temperature, and the CO$_2$ composition of the mixture. These predictions of ELM-11’s capture performance are compared with bench scale breakthrough curve experiments. Under investigation is the separation of CO$_2$ from CO$_2$/N$_2$, CO$_2$/CH$_4$, and CO$_2$/He gas mixtures. General implications regarding CO$_2$ capture on flexible metal-organic frameworks will also be discussed.
Thermodynamic Properties of Aqueous PEO-PPO-PEO Micelles of Varying Hydrophilicity with added Cisplatin Determined by Differential Scanning Calorimetry

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Differential Scanning Calorimetry was performed on a series of aqueous solutions of PEO-PPO-PEO (L101, P104, P105, and F108) amphiphiles in the low concentration regime (0-2%) to resolve the critical micelle concentrations (cmc) of the neat polymers. Work was done from 2% wt/v to 10% wt/v (in 2% wt/v increments) amphiphilic copolymer concentrations and co-formulated with cisplatin concentrations (0% wt/v-0.1% wt/v in 0.02% wt/v increments) to resolve any deviation in the enthalpy of micelle formation. Enthalpy-entropy compensation plots for each neat copolymer and each amphiphile solution mixed with cisplatin were obtained. Two types of behaviors were observed; a drug influenced compensation temperature profile (P104), and a drug invariant behavior (L101, P05 and F108) where the change in compensation temperature was less than 1°C. Only neat P104 was found to be profoundly influenced by the presence of cisplatin that must reorganize the interface between the hydrophobic and hydrophilic regions of the micelle. Adding cisplatin lowered \(T_{\text{compensation}}\) from 302.1 to 288.8 K.
SCE: System and Communication Engineering
Structured codes have been of great interest in recent years. Linear codes over algebraic fields have been studied extensively in the literature. Under certain constraints, codes with weaker algebraic structure (such as groups or rings) outperform linear codes. Nevertheless, it has been shown that for certain channels, group codes cannot achieve the symmetric capacity. Based on this observation a new structured coding scheme is proposed. We investigate the information theoretic performance limits for this strategy in multi-terminal communications. Achievability results are derived for lossless reconstruction of sum of two sources. In addition, a new rate region is presented for the problem of computation over multiple access channel. We show that the application of the new coding strategy, results in strict gains in terms of achievable rates in both settings.
Impact of community structure on cascades

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The threshold model is widely used to study the propagation of opinions and technologies in social networks. In this model individuals adopt the new behavior based on how many neighbors have already chosen it. We study cascades under the threshold model on sparse random graphs with community structure to see whether the existence of communities affects the number of individuals who finally adopt the new behavior. Specifically, we consider the permanent adoption model where nodes that have adopted the new behavior cannot change their state. When seeding a small number of agents with the new behavior, the community structure has little effect on the final proportion of people that adopt it, i.e., the contagion threshold is the same as if there were just one community. On the other hand, seeding a fraction of population with the new behavior has a significant impact on the cascade with the optimal seeding strategy depending on how strongly the communities are connected. In particular, when the communities are strongly connected, seeding in one community outperforms the symmetric seeding strategy that seeds equally in all communities.
Risky Business: Fine-grained Data Breach Prediction Using Business Profiles

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We aim to understand if, and to what extent, business details about an organization can help provide guidelines for better resource allocation across different preventive measures, in order to effectively protect, detect, and recover from, different forms of security incidents. Existing work on analyzing the distribution of risk across different incident categories, most notably Verizon's latest Data Breach Investigations Report, provide recommendations based solely on business sector information. In this study, we leverage a broader set of publicly available business details to provide a more fine-grained analysis. Specifically, we use incident reports collected in the VERIS Community Database (VCDB), as well as data from Alexa Web Information Service (AWIS), to train and test a sequence of classifiers/predictors. We show that compared to using business sector information alone, our method can achieve the same accuracy by allowing organizations to focus on a sparser set of incident types, thus achieving the same level of protection by spending less resources on security through more judicious prioritization.
New Lattice Codes for Multiple Descriptions

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A new coding scheme for the L-descriptions problem is proposed. The strategy allows the use of arbitrary (non-Gaussian) test channels. Nested lattices are utilized for quantization. The achievable rate-distortion (RD) region is calculated for both the case when all lattices are generated independently and when two of the nested lattices have the same inner code. In the process of deriving the RD region, new covering and packing bounds for using nested lattices are derived. It is shown that for setups with more than two descriptions, using nested lattice quantizers with the same inner code instead of independently generated codebooks results in gains.
Mechanism Design for Fair Allocation

Abhinav Sinha¹, Achilleas Anastasopoulos¹.
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Mechanism design for a social utility being the sum of agents' utilities (SoU) is a well-studied problem. There are, however, a number of problems of theoretical and practical interest where a designer may have a different objective than maximization of the SoU. One motivation for this is the desire for more equitable allocation of resources among agents. A second, more subtle, motivation is the fact that a fairer allocation indirectly implies less variation in taxes which can be desirable in a situation where (implicit) individual agent budgetary constraints make payment of large taxes unrealistic. Here we study a family of social utilities that provide fair allocation (with SoU being subsumed as an extreme case) and derive conditions under which Bayesian and Dominant strategy implementation is possible. Later a simple modification of the above mechanism is shown which can guarantee full Bayesian implementation. Through a numerical example it is shown that the proposed method can result in significant gains both in allocation fairness and tax reduction.
A Systematic Process for Evaluating Structured Perfect Bayesian Equilibria in Dynamic Games with Asymmetric Information

Deepanshu Vasal, Vijay Subramanian and Achilleas Anastasopoulos

We consider a finite horizon dynamic game with $N$ players who observe their types privately and take actions, which are publicly observed. Their actions and types jointly determine their instantaneous rewards. Since each player has a different information set, this is a dynamic game with asymmetric information and there is no known methodology to find perfect Bayesian equilibria (PBE) for such games in general. In this paper, we develop a methodology to obtain a class of PBE using a belief state based on common information of the players. We show a structural result that the common information can be summarized in this belief state such that any expected reward profile that can be achieved by any general strategy profile can also be achieved by a policy based on players' private information and this belief state. With this as our motivation, we state our main result that provides a two-step backward-forward inductive algorithm to find the class of PBE of this game that are based on this belief state. We refer to such equilibria as structured Bayesian perfect equilibria (SPBE). The backward inductive part of this algorithm defines an equilibrium generating function. Each period in the backward induction involves solving a fixed point equation on the space of probability simplexes for every possible belief on types. Then using this function, equilibrium strategies and beliefs are defined through a forward recursion.
Capacity of the General Trapdoor Channels

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The trapdoor channel is a special case of the binary unifilar channels, of which the state is determined by the previous input, output and state. Its capacity is derived in Permuter & Cuff. By formulating the feedback capacity as the average reward of a control system, they proved the capacity is equal to 0.6942 with the theory of Bellman equation. We further investigate the general trapdoor channels, which are the channels with only difference in the crossover probabilities, and show that in a specific range of crossover probabilities, the capacity remains the same. Moreover, in such region, the posterior belief on the state at the receiver, which generally could be any value in the interval [0 1], takes only four values if its initial value is one of those. This property simplifies the posterior matching scheme over the general trapdoor channels.
SIC: Signal and Image Processing, Computer Vision
Embracing Data Science with Graph Mining: Action Recommendations for Cyber Security, Clustering, and Beyond

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Many modern datasets are represented as graphs or stored in graph structures, ranging from social, cyber and physical network data, biological and chemical reactions to network flows and transportation system, among others. However, the graph nature prohibits utility from traditional data analysis techniques developed for multivariate data samples, both in theory and practice. This work aims to bridge this gap by proposing novel graph models and investigating their utility and limitation to graph data analysis. Moreover, we develop several efficient and effective graph mining methods involving graph data mining, action recommendations and interactive decision making, particularly for the following fields: (a) Cyber intrusion detection (b) Implementation of action recommendations against real-time cyber attacks using cloud services (c) Data-driven network resilience enhancement (d) Automated model order selection for graph clustering (e) Interactive graph data analysis. For the theory side, we establish fundamental principles that govern the feasibility of graph models and develop efficient graph mining algorithms with performance guarantees. For the practice side, we demonstrate the success of the proposed data-driven graph mining methods in the aforementioned fields.
Consistency of a Fixed Bandwidth Kernel Density Estimator

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We show a consistency result of a kernel density estimator with fixed bandwidth. This estimator is a linear combination of radial kernel functions and differs from the standard Kernel Density Estimator in that it allows the scaling coefficients to be negative. While the explicit form of the rates of convergence has eluded us so far, we show intermediate results towards their calculation.
Kernel Approximation for Transfer Learning

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We consider the problem of assigning class labels to an unlabelled test data set, given several labelled training data sets drawn from similar distributions. This problem arises in several applications where data distributions fluctuate because of biological, technical, or other sources of variation. There is a distribution-free, kernel-based approach to the problem, which involves identifying an appropriate reproducing kernel Hilbert space and optimizing a regularized empirical risk over the space. But as dataset size increases, computational complexity of the SVM solver used in the above approach can be quadratic or cubic in terms of number of samples. We propose a kernel approximation technique which reduces the time complexity of the solver to linear in terms of number of samples. Kernel methods project input data points into high dimensional feature space (infinite-dimensional in case of Gaussian kernel) and find the optimal hyperplane in that feature space. Using kernel approximation technique such as random Fourier features we map the input data to a randomized low-dimensional feature space and then apply existing fast linear SVM solvers. Experimental results are shown on few datasets.
Modeling 3D error propagation from 2D visual tracking with applications in quadrotor tracking

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3D pose estimation from 2D vision is a core module in control, mapping, navigation and other robotics applications. Visual tracking in monocular videos remains a challenge; understanding how the 2D tracking propagates to 3D pose error is critical to engineering reliable robotic systems. We hence explore models for projecting 2D visual tracking error into 3D pose error. To this end, we move from simple, centroid-based models to complex, bounding box-based models, successively relaxing assumptions on the configuration of the object. We apply these proposed models to monocular visual tracking and 3D pose estimation in two application domains: tethered quadrotors and autonomous cars. We evaluate our proposed pose estimation models in both the domains.
Meta learning of bounds on the Bayes classifier error

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Meta learning uses information from base learners (e.g. classifiers or estimators) as well as information about the learning problem to improve upon the performance of a single base learner. For example, the Bayes error rate of a given feature space, if known, can be used to aid in choosing a classifier, as well as in feature selection and model selection for the base classifiers and the meta classifier. Recent work in the field of $f$-divergence functional estimation has led to the development of simple and rapidly converging estimators that can be used to estimate various bounds on the Bayes error. We estimate multiple bounds on the Bayes error using a non-parametric estimator that applies meta learning to slowly converging plug-in estimators to obtain the parametric convergence rate. We compare the estimated bounds empirically on simulated data and then estimate the tighter bounds on features extracted from an image patch analysis of sunspot continuum and magnetogram images.
The accuracy of singular vectors of thresholded low-rank plus noise plus outlier matrices

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We consider the problem of reliably recovering a fixed, unknown low-rank signal matrix corrupted by random noise and outliers. In particular, motivated by recent work on sparse signal estimation, we study the families of low-rank matrix estimators produced by soft or hard thresholding, respectively, the elements of the observed matrix. We evaluate the performance of these data-driven estimators by comparing the asymptotic accuracy of their singular vectors to an oracle estimator where one replaces the known outlier-corrupted entries of the observed matrix with zeros. Our analysis yields two sufficiency results. First, in the sparse outlier regime, we identify sufficient conditions on the statistics of the noise/outlier matrices and the thresholding parameter for which the asymptotic accuracy of both the soft and hard thresholding estimators are equal to the oracle estimator. Second, in the dense outlier regime, we identify analogous sufficient conditions for which the accuracy of the hard-thresholding and oracle estimators are equal, and we show that, unlike the sparse outlier regime, these conditions are not sufficient to establish the equivalence of the soft-thresholding and oracle estimators. Indeed, we empirically show that soft-thresholding is sub-optimal in the dense outlier setting. Our analysis holds for a wide class of models; we assume only that the entries of the noise and outlier matrices are independent with bounded moments.
Sparse Equisigned PCA

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Principal Component Analysis (PCA) is a dimensionality reduction technique for multivariate data. However, when the dimensionality of the data is of similar order to the number of samples, PCA breaks down: the eigenvectors of the sample covariance matrix are inconsistent estimates of the population eigenvectors. Nevertheless, when the eigenvectors are sparse, there are consistent estimators. Unfortunately, many such estimators are multi-stage procedures or are complicated iterative methods. Placing a second structural assumption on the data leads to a simplification: if the data are either non-negative or non-positive, a one-stage algorithm yields consistent estimates of the population eigenvectors. We examine the consistency, performance, and theoretical limits of eigenvector estimation under these conditions.
New image reconstruction algorithm guided by local gradient SVD

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We propose a new image reconstruction algorithm that alternates between minimizing a convex objective function and choosing new objective function parameters. The parameters are chosen using the gradient of the previous image estimate. Specifically, for each pixel, a singular value decomposition is performed on a data matrix consisting of local gradient vectors. If the singular values are similar in size, then objective function parameters are chosen to locally penalize image differences in an isotropic fashion. However, if the first singular value is much larger than the second, then parameters are chosen anisotropically in order to locally penalize image differences in directions orthogonal to the first singular vector. Our results improve upon previous algorithms for reconstructing images from their “Manhattan” image samples, where 2D data is sampled along evenly spaced rows and columns of pixels.
EmoShapelets: Capturing Local Dynamics of Audio-visual Affective Speech

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Automatic recognition of emotion in speech is an active area of research. One of the important open challenges relates to how the emotional characteristics of speech change in time. Past research has demonstrated the importance of capturing global dynamics (across an entire utterance) and local dynamics (within segments of an utterance). In this paper, we propose a novel concept, EmoShapelets, to capture the local dynamics in speech. EmoShapelets capture changes in emotion that occur within utterances. We propose a framework to generate, update, and select EmoShapelets. We also demonstrate the discriminative power of EmoShapelets by using them with various classifiers to achieve comparable results with the state-of-the-art systems on the IEMOCAP dataset. EmoShapelets can serve as basic units of emotion expression and provide additional evidence supporting the existence of local patterns of emotion underlying human communication.
Robust Orbit Determination: A Machine Learning Approach

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Orbit determination involves estimation of a non-linear mapping from feature vectors associated with the position of the spacecraft and its orbital parameters. The de facto standard of orbit determination in real-world scenarios for spacecraft has been linearized estimators such as the extended Kalman filter. Such an estimator, while very accurate and convergent over its linear region, is hard to generalize over arbitrary gravitational potentials and diverse sets of measurements. It is also challenging to perform exact mathematical characterizations of the Kalman filter performance over such general systems. We present a new approach to orbit determination as a learning problem involving distribution regression and provide some associated analysis of the technique. We also show that it can be extended for orbit estimation of multiple spacecraft from ground station networks.
Algorithms for Estimation of Low Rank Matrices with Kronecker Structured Singular Vectors

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We consider the problem of estimating the singular vectors of low-rank signal matrices buried in noise, in the setting where the singular vectors of the signal are assumed to be Kronecker products of unknown vectors. We propose four algorithms for the estimation of such singular vectors, and analyze the performance limits of the proposed algorithms. We validate our theoretical findings with numerical simulations. We illustrate improved clutter suppression in a Space-Time Adaptive Processing beamforming application using singular vector estimates from our newly proposed algorithms, relative to using the canonical SVD based singular vector estimate.
Can humans fly? Emphatically no. Can cars eat? Again, absolutely not. Yet, these absurd inferences result from the current disregard for particular types of actors in action understanding. There is no work we know of on simultaneously inferring actors and actions in the video, not to mention a dataset to experiment with. Our paper hence marks the first effort in the computer vision community to jointly consider various types of actors undergoing various actions. To start with the problem, we collect a dataset of 3782 short videos along with 31 temporally untrimmed long videos from YouTube. We label short videos with pixel-level actors and actions, and label long videos with bounding box-level actors and actions over time. We formulate the general actor-action understanding problem and instantiate it at various granularities: both video-level single- and multiple-label actor-action recognition and pixel-level actor-action semantic segmentation. Our experiments demonstrate that inference jointly over actors and actions outperforms inference independently over them, and hence concludes our argument of the value of explicit consideration of various actors in comprehensive action understanding.
Recognizing Emotion from Singing and Speaking Using Shared Models

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Speech and song are two types of vocal communications that are closely related to each other. While significant progress has been made in both speech and music emotion recognition, few works have concentrated on building a shared emotion recognition model for both speech and song. In this paper, we propose three shared emotion recognition models for speech and song: a simple model, a single-task hierarchical model, and a multi-task hierarchical model. We study the commonalities and differences present in emotion expression across these two communication domains. We compare the performance across different settings, investigate the relationship between evaluator agreement rate and classification accuracy, and analyze the classification performance of individual feature groups. Our results show that the multi-task model classifies emotion more accurately compared to single-task models when the same set of features is used. This suggests that although spoken and sung emotion recognition tasks are different, they are related, and can be considered together. The results demonstrate that utterances with lower agreement rate and emotions with low activation benefit the most from multi-task learning. Visual features appear to be more similar across spoken and sung emotion expression, compared to acoustic features.
Richard and Eleanor Towner
Prizes for Outstanding Ph.D.
Research Poster Session
Q-Enhanced Depletion-mediated AlGaN/GaN Resonators

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AlGaN/GaN hetero-structures have attracted significant attention recently due to their superior material properties. In the last decades, they were mainly used in power amplifiers in base stations and for optoelectronic application in LEDs and lasers. GaN also exhibits strong piezoelectric properties, making it a perfect candidate as an acoustic device, which is not extensively investigated to date. In order to fully unlock the potential of GaN, we look at the combined acousto-electrical properties of GaN material systems.

We report on frequency tunable AlGaN/GaN acoustic resonators that utilize piezoelectric actuation based on depletion-mediated strain in the AlGaN layer and piezo-resistive readout based on integrated AlGaN/GaN HEMTs. The actuation electrodes are Ni/Au Schottky contacts and the readout electrodes Ti/Al/Ti/Au Ohmic contacts, placed in the middle of the acoustic cavity. We observe a significant Quality factor ($Q$) enhancement as the DC voltage applied to the drain-source of the HEMT increases. The 9th-order width extensioinal resonance mode at $\sim$719 MHz shows $Q$ enhancement from 1,710 at $V_{DS}=4$ V to 13,851 at $V_{DS}=9$ V, marking the highest ($frequency \times Q$) reported for any GaN-based resonator to date. Furthermore, wide-range frequency tuning is achieved by flowing DC current through the Ohmic contacts, causing large elastic modulus change due to Joule heating. More than 2500 ppm of frequency tuning is achieved at $V_{DS}=9$ V. Such devices can be used as self-sustained oscillators as well as in-situ temperature sensors where the resonance frequency shift is an indicator of the temperature rise in the suspended HEMT channel.
Balancing Design Freedom and Brand Recognition in the Evolution of Automotive Brand Styling

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Designers faced with the task of developing the latest model of a brand must balance several considerations. The design must be novel and express attributes important to the customers, while also recognizable as a representative of the brand. This balancing is left to the intuition of the designers, who must anticipate how customers will perceive the new design. Oftentimes, the design freedom used to meet an attribute can compromise the recognition of the product as a member of the brand. In this paper, an experiment is conducted measuring change in ten styling attributes common to both design freedom and brand recognition for automotive designs, using crowdsourced customer responses to 2D and 3D morphable vehicle designs created and presented interactively. Results show that, while brand recognition is highly dependent on the particular manufacturer, tradeoffs between design freedom and brand recognition may be measured using hierarchical statistical predictive models to inform strategic design decisions.
Robust and Efficient hp-adaptation for Discontinuous Galerkin Methods

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As computers and numerical methods become more powerful, it is equally important to control numerical error and thereby focus the computational effort on appropriate regions of the simulation. With increasingly complex simulations, these regions and their effect on the outputs of interest, such as lift and drag on an airplane, become nearly impossible to predict a priori. Here we focus on high-order finite element methods for computational fluid dynamics, which have recently become popular for their enhanced accuracy. Our work sets out to both devise a new method with even lower computational cost and automatically adapt the mesh and solution representation to optimize an output of interest from the simulation. Therefore, in this work we present the first primal hybridized discontinuous Galerkin method for systems of equations, such as Navier-Stokes. This method has fewer unknowns than any previous discontinuous Galerkin method, leading to a faster solution time, while still maintaining the optimal convergence and error estimation properties for which these methods are celebrated. We couple this numerical method with a family of hp-adaptation procedures also developed here, which automatically distribute the mesh resolution and solution order simultaneously to achieve the highest accuracy in an output of interest. The hp methods compute inexpensive local sub-problems in parallel, eliminating heuristics and allowing these to apply to any discontinuous Galerkin method.
Due to their high power densities (up to 15 kW kg⁻¹), energy densities (up to 14 Wh kg⁻¹), and long cycle life (e.g., >1,000,000), electrochemical capacitors or “supercapacitors” are attractive for a number of applications including use in memory back-up devices, portable electronics, uninterruptible power supplies, electrified vehicles and large industrial equipment. In terms of their specific energy and specific power, they fill the gap created by conventional capacitors and batteries, and can be used in hybrid configurations to manage short, high power pulses, thereby minimizing stresses on the primary energy-storage devices. Nevertheless, the high cost and moderate energy density of current commercial supercapacitors limit their practical applications. In order to increase the energy density and lower the cost, the capacitance and/or the operating voltage must be increased. Research described in this dissertation aims to investigate the use of nanostructured early transition-metal carbides and nitrides as electrode materials for supercapacitors. These high-surface-area materials possess very high capacitances, wide voltage windows, and hold promise for use in low cost, high energy density supercapacitors. The mechanism for charge storage in early transition-metal carbides and nitrides has been the subject of a number of recent investigations. The full exploitation of these materials would benefit from a better understanding of the charge-storage mechanism. The goal of this research is to enhance our understanding of the charge-storage mechanism for early transition-metal carbides and nitrides based supercapacitor electrode materials by developing detailed relationships between their capacitive, compositional and structural properties using a combination of ex-situ and in-situ experimental and electrochemical techniques.
Examining the Role of Microstructure and Environment on Small Fatigue Crack Growth Behavior in Ti-6242S

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Fatigue lifetime in the very high cycle fatigue (VHCF) regime is primarily consumed by the cycles needed to initiate and propagate a microstructurally small crack. Although strains are nominally elastic, local cyclic plastic strain accumulation occurs at the micro-scale and drives crack initiation and early crack growth behavior. Furthermore, fatigue crack formation is extremely sensitive to the microstructural landscape and environmental influences. The effects of both microstructure and environment on fatigue damage accumulation mechanisms were investigated in the near alpha titanium alloy, Ti-6242S. An experimental methodology was developed which combines ultrasonic fatigue at 20 kHz, scanning electron microscopy, and Digital Image Correlation (DIC) techniques to study the evolution of full-field strain mappings at the micro-scale. Crack initiation and propagation behavior in relation to microstructural features, such as high angle $\alpha'/\alpha$ grain boundaries, was correlated with cyclic strain accumulation as measured by in-situ scanning electron microscopy DIC techniques. The evolution of small-scale strain fields at crack tips and in the microstructural neighborhood of the advancing crack was examined. The influence of environment and the presence of microstructural features on strain localization, crack initiation, and early crack propagation will be discussed.
Simulations of shocks and interfaces in highly compressible multiphase flows

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From tiny bubbles collapsing in human tissue to massive stars exploding, I study fluids that mix in high speed flows to accelerate the success of many engineering applications, including fusion energy and supersonic combustion, and our comprehension of astrophysical and planetary formation processes. My research is also applicable to the development of biomedical technologies, including non-invasive medical treatments that use ultrasound to induce bubble collapse in tissue to destroy tumors or deliver genes to specific cells. However, laboratory experiments of these flows are challenging because the initial conditions and material properties are difficult to control, modern diagnostics are unable to resolve the flow dynamics and conditions, and experiments of these flows are expensive. To resolve these difficulties, I present (i) novel numerical methods to capture accurately the problems’ multiphysics nature; (ii) modern high-performance computing paradigms to resolve the disparate time and length scales of the physical processes; (iii) simulations and theoretical models of a blast wave, an instantaneous acceleration followed by a time-dependent deceleration, interacting with a sinusoidal perturbation at an interface between two fluids. The hydrodynamic instability, initiated by the blast wave, induces mixing between the fluids. This is particularly relevant to the studies of supernova collapse and inertial confinement fusion. Combining the three fields of high-performance computing, numerical methods, and multiphysics modeling in a consistent framework, we increase our scientific understanding of multiphase flows particularly relevant to novel manufacturing techniques, enhanced combustion processes, more robust naval propellers, and biomedical treatments.
Dynamic Personalized Monitoring and Treatment Control of Glaucoma

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To effectively manage chronic disease patients, clinicians must know (1) how to monitor each patient (i.e., when to schedule the next visit and which tests to take), and (2) how to control the disease (i.e., what levels of controllable risk factors will sufficiently slow progression). Our research addresses these questions simultaneously and optimally by employing linear quadratic Gaussian state space systems modeling and optimal control of measurement adaptive systems. The model is able to (1) specify the optimal timing of each office visit and the appropriate suite of tests to perform at that visit [disease monitoring], and (2) identify optimal target levels for key disease risk factors to slow the rate of disease progression dynamics [treatment control]. For the new quadratic objective of minimizing disease progression over time, we show that the classical two-way separation of estimation and control holds, thereby making a previously intractable problem solvable by decomposition into two separate, tractable problems while maintaining optimality. The resulting optimization is applied to the management of glaucoma. Based on data from two large randomized clinical trials, we found that fast-progressing patients, who are most at risk for disease progression, show an average of 38% to 58% less loss of peripheral vision per year, leading to 21% to 32% better quality of vision after 10 years when compared to existing treatment controls attained in the clinical trials. This methodology can be applied to a broad range of chronic diseases to optimally devise patient-specific monitoring and treatment plans.
Can machines interact with humans, as naturally as humans interact with each other? My main research interest is the automatic analysis of human behavior during real-world interactions. In particular my PhD work focuses on developing systems for automatic sensing, quantification, and interpretation of an individual’s emotion based on their face and voice during dyadic (two-person) interaction. The main challenge of developing such systems is that the expression of emotion changes over time. Therefore, it is important to accurately quantify dynamics and structure of affective behavior. To this aim, the presented work focuses on time-series segmentation and analysis methods. First, we studied how to represent and analyze dynamic facial movement when a person is speaking. Facial movements are modulated by both emotion and speech (e.g., similarity in facial movements when a person is saying ‘cheese’ vs. smiling). The result of this confusion is a decrease in performance of facial emotion recognition systems. We proposed a new unsupervised segmentation method that does not require any transcripts as in traditional methods. Our method also significantly improves the prediction accuracy and interpretability of facial emotion recognition systems. Second, we developed a system that quantitatively represents how estimated emotions change over time. We hypothesized that emotion changes at the sentence level have emotion-specific variations that can be used to differentiate emotion classes. We found that the variations help improving emotion recognition rates compared with baseline models. Our results provide insight into dynamics of affective cues embedded within audio-visual data and contribute to interactive technologies.
Hard capacity constraints and aggregated demand parameters have been used for decades in facility location modeling and planning. However, we argue that such a framework is unrealistic since 1) facility managers have many operational tools that allow facilities to accept demand in excess of the capacity constraints for short periods of time and 2) aggregated demand parameters don’t capture the likelihood that demand may, in fact, exceed the stated capacity constraints. To address this, we use inventory as a short-term mitigation strategy and allow the models to directly utilize disaggregated daily demand data, which inherently capture demand stochasticity. We present a basic model in which demand from a node must be assigned to a single facility for all time intervals under consideration. If more demand arrives at a facility than the facility can process in a day, the remaining demand will simply be held in inventory and processed the following day. We show that the location decisions made without inventory allowances are different from, and in some cases significantly worse than, those suggested by our model. We then extend the basic model to allow for day-of-the-week assignments which can account for time-varying demand or for facilities with day-to-day variations in their daily processing capacity levels. We show that adding this flexibility to the model can further reduce costs and enhance system performance. The models we present have applications in a number of areas, including locating blood testing facilities and Amazon Inc. warehouses.
Improving fMRI Scans Using Low Rank Modeling

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Functional MRI (fMRI) has the potential to be used as a powerful biomarker for the diagnosis of neurological disorders. Neurological disorders often have overlapping symptoms, but recent studies have suggested that they can be differentiated by looking at group-level changes in so-called functional networks. However, extending these group-level results to the single-subject setting is problematic due to the large quantity of noise in individual subject scans. The dominant parts of the noise are the cardiac and respiratory rhythms, which are difficult to remove since fMRI scans have a sampling rate lower than the requisite Shannon-Nyquist sampling rate, so these physiological signals alias on top of the lower-frequency neurological signals of interest. We propose to apply compressed sensing ideas to resolve this problem. We implement a random sampling pattern and then reconstruct the images by assuming that the data lies in a lower dimensional space. The intersection of possible low-dimensional objects and those that are consistent with the acquired data provides a high-temporal resolution estimate of the object, from which the cardiac and respiratory rhythms can be removed. We validate the approach on a prospectively undersampled fMRI scan with a finger tapping paradigm, showing successful estimation of signals in the respiratory frequency band while preserving the functional activation of interest.
Provision of Non-Excludable Goods on Networks: Incentives, Exit Equilibria, and Applications to Cyber-Security

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In a system of interdependent users, the security of an entity is affected not only by that user’s effort towards securing her system, but also by the security decisions of other users. The provision of security in such environment is modeled as a public good provision problem, and is referred to as a security game. In this work, we propose the notion of exit equilibrium to study users’ voluntary participation in mechanisms for optimal provision of non-excludable public goods such as security. We show the fundamental result that, due to the non-excludability of these goods, there exists no reliable mechanism which can incentivize the socially optimal investment profile, while ensuring voluntary participation and maintaining a weakly balanced budget, for all instances of the problem. To better understand the features of the games that lead to this result, we consider the class of weighted effort games, and apply the two well-known Pivotal (VCG) and Externality mechanisms. Through analysis and simulation, we identify the effects of several features of the problem environment, including diversity in user types, multiplicity of exit equilibria, and users’ self-dependence levels, on the performance of these mechanisms. We further identify a connection between users’ centralities in their interdependence network, and their efforts at different interior equilibrium profiles of these games. These characterizations separate the effects of incoming and outgoing dependencies, as well as the influence of paths of different length, on users’ investments in security. We discuss some conceptual and practical implications of this centrality-effort connection.
Energy efficient processing through fine-grained heterogeneity

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From data centers, which draw megawatts of power, to mobile phones, where battery life is precious to all users, fundamental increases in energy efficiency are critical to enable continued performance scaling. While the number of transistors on chips is rapidly increasing, the rising power density prevents us from utilizing them simultaneously. Computer architects sought to turn this limitation into an opportunity by introducing several heterogeneous accelerators on a chip, where each accelerator is customized to efficiently execute specific functions for specific applications. Such customization exploits code regularity, like that in scientific applications. However, the current explosion of application space, coupled with constant innovation, make it imperative to seek more general-purpose solutions that can efficiently execute any program, from web browsers to operating systems.

General-purpose applications can have very diverse and irregular behavior, making processor customization difficult. However, close inspection revealed that most applications exhibit regular phased behavior at granularities of hundreds of instructions. These phases have varied behavior and each phase executes with varying efficiency on differently customized general-purpose hardware. The discovery of regularity at a fine granularity inspired us to design the Composite Core. This design achieves high performance with energy-efficiency by pushing the idea of customization within the processor. This allows the application to switch between heterogeneous compute elements at an extremely fine granularity. We complement this with novel, low-overhead scheduling mechanisms that maximize an application's time in energy-efficient modes, thus maximizing the energy conserved.

The architecture and scheduler together enable Composite Cores to achieve energy-efficient execution for general-purpose programs.
Screening for smuggled nuclear weapons with novel radiation detection systems at our country’s borders

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The federal government has decreed that all vehicles and cargo containers entering this country must be screened for the presence of nuclear and radiological material to protect the United States from terrorist attacks. Radiation portal monitors (RPMs) are widely deployed at our border crossings, ports of entry and airports. RPMs detect the presence of gamma-rays and neutrons, and distinguish elevated count rates from natural background radiation. The University of Michigan has developed and tested new RPMs with unconventional detector materials and novel data analysis algorithms to address two critical issues with current RPM technology. First, currently deployed RPMs rely on $^3$He gas as the detection medium for neutrons. This material is solely produced as a by-product of the decay of American and Russian tritium stockpiles. These finite supplies from the nuclear weapons complex are expected to be depleted by the mid-century, thus leading researchers to scramble for alternative neutron detectors for both homeland security and myriad other applications. Our design uses liquid organic scintillation detectors that are capable of measuring and distinguishing gamma-rays and neutrons through pulse shape discrimination. Second, nuisance alarms present another issue with currently deployed RPMs. Many common goods, like tobacco, granite and ceramics, contain naturally radioactive isotopes which obstructively trigger RPM alarms. Secondary inspections can confirm that a truck is carrying tobacco and not plutonium, but each of these additional inspections consumes the precious time and resources of our border patrol. Our more intelligent RPM provides on-the-fly identification of any radiation source passing through the RPM.
Understanding of Workers’ Physical Demands and Their Impact on Construction Operations

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Construction is labor intensive, involving physically demanding manual tasks. Excessive physical demands have had an adversarial impact on workers' performance, safety and health, leading to productivity loss, human errors, unsafe actions (associated with 80%–90% of accidents) and work-related musculoskeletal disorders (account for 24% of all non-fatal injuries) in construction. Despite significant research efforts (e.g., surveys, observational methods, direct measurements) to identify excessive physical demands during occupational tasks, however, limitations exist when these methods are applied in real conditions due to the difficulty of field data collection on workers’ activities. In addition, as these methods focus on evaluation of ergonomic risks, the impact of excessive demands on performance have not been fully understood. To address this issue, we propose a comprehensive framework for 1) evaluating physical demands by using computer vision techniques and 2) understanding their potential impact on construction operation through a computer simulation. Specifically, vision-based action recognition and motion capture provides a non-invasive and automated means to collect workers’ postures and motions that can be used to identify postural and biomechanical stresses during performing tasks. In addition, a simulation-based approach that combines a Discrete Event Simulation (DES) with biomechanical and fatigue models allows to capture interactive effects between excessive physical demands and construction performance (e.g., productivity, cost), considering limited human physical capacity (e.g., muscle fatigue). Ultimately, the proposed framework helps to better understand the relationship between physical demands and capabilities and their impact on construction operations, which in turn enables a more effective management of work demands.
SnSe: a multifunctional material with exceptional thermoelectric and photovoltaic performance

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SnSe is a layered IV–VI compound semiconductor that can be exfoliated to form two-dimensional materials. While atomically thin transition metal dichalcogenides display unique electronic and optoelectronic properties, little is known about the properties of few-layer IV–VI materials. In addition, bulk single-crystal SnSe shows extraordinary thermoelectric performance with record figure-of-merit values as high as 2.6. In this work, we use predictive calculations based on density functional and many-body perturbation theory to study the electronic and optical properties of single-layer, double-layer, and bulk SnSe. The interplay of spin–orbit coupling and lack of inversion symmetry in the monolayer structures results in anisotropic spin splitting of the energy bands, with potential applications in directionally dependent spin transport. We show that single-layer and double-layer SnSe exhibit unusually strong optical absorbance in the visible range. We also calculate the thermoelectric transport coefficients of SnSe as a function of doping concentration and temperature to understand the previous experimental measurements, and found SnSe exhibits optimal thermoelectric performance at high temperature when doped in the $10^{19}$–$10^{20}$ cm\textsuperscript{-3} range. Our results suggest that SnSe is a multifunctional material that has potential applications in efficient and flexible ultrathin-film photovoltaic devices that operate in combination with waste-heat harvesting.
Modeling the multi-decadal climatology of the extratropical transition of tropical cyclones in the North Atlantic

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The long-term climatology of the extratropical transition of tropical cyclones is analyzed. Extratropical transition occurs as a tropical cyclone moves poleward and merges with the large-scale flow. The cyclone becomes less symmetric and the structure of the storm gradually changes to a baroclinic weather system. These transitions inhibit accurate weather prediction and can create extreme weather events with intense rain, wind, and storm surges. The Community Atmosphere Model is used with the variable-resolution Spectral Element dynamical core. Over the North Atlantic tropics, high-resolution 28 km grid spacing allows the model to sufficiently resolve the structure of tropical cyclones, including sharp gradients in the eye wall. As the tropical cyclone travels beyond the high-resolution region, the grid spacing transitions to 110 km. This approach is computationally efficient, yet the high-resolution region successfully simulates the extratropical transition of cyclones in the Atlantic Ocean. The 23-year simulation utilizes prescribed sea surface temperatures and sea ice according to the Atmospheric Model Intercomparison Project protocol. The results are compared to observations using reanalysis data from the National Centers for Environmental Prediction. In particular, we evaluate the long-term climatology of extratropical transition throughout the simulations, as well as the seasonal cycle of tropical cyclone formation and transition. Phase space analysis follows the structural evolution of storms as they transition from symmetric, warm-core tropical cyclones to asymmetric, cold-core extratropical storms. An individual analysis of selected storms demonstrates the development of cyclone asymmetries and cold-core structures as the storms gradually undergo extratropical transition.
Quantifying Cell Membrane-Polymer Interactions: Implications for Endosomal Escape and Successful Gene Expression

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Gene therapy can potentially treat congenital disorders (e.g. cystic fibrosis) and cancer. Successful gene therapy is hindered by the lack of safe and effective delivery agents (vectors). Our limited understanding of how polymer-DNA complexes, termed polyplexes, are internalized into cells and transported to the nucleus hinders the development of new non-viral vectors. We have developed a new strategy for the release of DNA from the endosome, transport to the nucleus, and minimization of vector-induced cytotoxicity based on the interaction of free L-PEI vector with the cell's lipid bilayers. This new approach was developed using studies that tracked the transport of intact DNA in cells and quantitatively measured vector-cell membrane interactions. Specifically, a major limitation with present imaging techniques is their inability to distinguish functional intact DNA from degraded DNA. To address this limitation, we used a novel DNA oligo nucleotide molecular beacon (OMB) labeled with a dye pair that exhibits Forester Resonance Energy Transfer (FRET). This OMB emits with greater intensity in the red region when intact and emits with greater intensity in the green region when cleaved. OMBs were delivered using various polycationic polymers. Flow cytometry and confocal microscopy were used to quantify the intracellular degradation of the OMB. When combined with our studies that provided the first available partition constants of cationic polymers and polyplexes in living cell membranes, these experiments provide a novel new strategy that emphasizes the role of cell membrane-polymer interactions in driving successful gene expression.
A High Fidelity Multiphysics Modeling Framework and Validation of CRUD Deposition on Nuclear Fuel Rods

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Corrosion products on fuel cladding surface have had a significant impact on reactor operation. These types of deposits are referred to as CRUD (Chalk River Unidentified Deposit) and can lead to CIPS (CRUD-induced power shift), as a consequence of the accumulation of solid boron phases on the surface of the fuel pins. CRUD can also lead to fuel failure due to increased cladding temperature and accelerated corrosion, known as CILC (CRUD-induced localized corrosion). The prediction of these occurrences requires a comprehensive understanding of local thermal hydraulic and chemical processes occurring in close proximity to the cladding surface, as well as their driving factors. Such factors include the power distribution, fluid turbulence, and corrosion product concentration in the reactor coolant, as well as the feedbacks between thermal hydraulics, chemistry and neutronics. To correctly capture the underlying physics and corresponding feedbacks, multiphysics simulations are necessary that combine heat transfer and fluid dynamics, coolant chemistry, neutron transport, and nuclide transmutation. Therefore, a multiphysics framework was developed, and a systematic evaluation of the coupled physics is completed to determine the associated sensitivity of the CRUD predictions to boundary conditions and the temporal coupling approach. Initial validation of the coupled framework has been completed by comparing simulation predictions to Seabrook Nuclear Power Plant data. During Seabrook Cycle 5, CIPS was observed and several CILC failures occurred. Measurements of the clad oxide thickness on both failed and non-failed rods, together with data on the CRUD scrapes of peripheral rods, are used in the comparison.
Observations of vortex merger and growth reduction in a dual-mode, supersonic Kelvin-Helmholtz instability experiment

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The Kelvin-Helmholtz instability is a basic hydrodynamic process that generates vortical structures and turbulence at an interface with shear flow. This instability is ubiquitous in natural and engineering systems including protoplanetary disks, stellar environments, and laboratory plasmas. In a supersonic shear flow, compressibility inhibits the linear growth rate of the Kelvin-Helmholtz instability. Laser-driven hydrodynamic experiments allow us to study the contribution of compressibility with well-controlled and well-characterized initial conditions. Detailed measurements of modulation amplitude growth and vortex merger can validate and benchmark existing theories and hydrodynamic models. This experiment provides the first measurements of the vortex merger rate of well-characterized seed perturbations evolving under the influence of the Kelvin-Helmholtz instability in a supersonic flow. These data were obtained by utilizing a sustained laser pulse to drive a steady shockwave into low-density carbon foam, introducing shear along a precision-machined plastic interface. The evolution and merger of the modulations was measured with x-ray radiography and reproduced with 2D hydrodynamic simulations.
Inorganic chiral nanomaterials: design strategies and origin of homochirality

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The importance of chirality was discovered in 1963, when the critical birth defects were caused by the presence of wrong handed thalidomide in a drug that was supposed to cure morning sickness. Considering that chiral molecular drugs shared one-third of all drug sales worldwide in 2000, chiral selective synthesis and separation of enantiomers are critical for disease diagnosis and therapy in the pharmaceutical industry. Recently, chirality of inorganic nanomaterials has been considered of much importance because they are of prime fundamental and practical interest due to the favorable power-law scaling of near-field enhancements. A further motivation to study chirality of inorganic nanostructures is to discover the origin of homochirality in natural compounds. The prevalence of only L-type amino acids and D-type sugars in nature is well-known example of homochirality. This dominant existence of only one of the two enantiomers among natural products has kept scientific attentions for decades. Several chemical routes are being debated, including chiral amplification and influence of circularly polarized light (CPL) from the cosmos. Chemical reactions affected by spin angular momenta of circularly polarized photons are rare and display low enantiomeric excess. Because of high optical and chemical activity, nanoparticles (NPs) signifies the possibility of converting spin angular momenta of absorbed photons into structural changes of nanoscale materials by self-assembling. However, such processes are currently unknown. Here, we demonstrate that CPL strongly affects the nature of self-assembly of racemic CdTe NPs. In particular, illumination of NP dispersions with right- and left-handed CPL induces the formation of right- and left-handed twisted nanoribbons, respectively. Enantiomeric excess of such reactions exceeds 30% which is ~10 times higher than other CPL-induced reactions. This observation of imprinting the polarization information of incident photons by NPs opens new pathways for the synthesis of chiral photonic materials and allows for better understanding of the origins of biomolecular homochirality.
Rapid, puncture-initiated healing via oxygen-mediated polymerization

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Autonomously-healing materials, capable of self-repair when damaged, are of tremendous interest as a means to extend product lifetime and prevent catastrophic failure; indeed, numerous fields, including aerospace, automotive, and biomedical, would greatly benefit from their development. Although several promising healing mechanisms have been developed, typically employing a liquid-to-solid transition effected by polymerization, sluggish reaction rates preclude their adoption in many applications, such as the self-healing of micrometeoroid damage in space exploration habitats where rapid atmosphere loss poses a critical and immediate hazard. We have developed a promising approach to greatly decrease the time required for autonomous repair by utilizing oxygen, ubiquitous in human-occupied environments, as an environmentally-borne polymerization initiation stimulus. In conjunction with radical-generating, oxygen-sensitive alkylboranes, oxygen is used to initiate thiol–ene polymerization, a radical-mediated, step-growth reaction with extraordinary resistance to oxygen inhibition. Real-time infrared spectroscopy demonstrates solid polymer formation from a liquid thiol–ene-borane formulation within seconds of oxygen exposure. These thiol–ene-borane formulations were sandwiched between solid polymer support panels, and the self-healing capability of the tri-layered structure was examined by ballistics testing. As evidence for rapid polymerization upon penetration, high-speed videography revealed a rapid viscosity increase, and high-speed thermal infrared imaging indicated an exothermic reaction, attributed to the oxygen-mediated polymerization. Furthermore, post-penetration images demonstrate the formation of solid polymeric material in the bullet-induced hole. These ballistics testing results confirm the viability of \textit{in situ} oxygen-mediated polymerization as a rapid, puncture-initiated autonomous healing mechanism.
Optical Properties and Optoelectronic Applications of Nano-size Metallic Films and Metamaterials

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Technology progress is continuously driven by advances in materials and device design concepts. Optoelectronic devices have been widely used nowadays, ranging from military/industry applications such as lasers, photo-detectors to our daily merchandises such as displays, solar panels, and light emitting diodes (LEDs), etc. Future optoelectronic devices should have compact size, be flexible, and have high efficiency and robust performance. All these merits require developments in their constituting materials as well as fundamental working principles. In this presentation, new optical materials and device concepts are investigated. A new kind of silver film: aluminum-doped silver is discovered and its properties are studied. The film is ultra-thin, ultra-smooth, low loss, and is thermally robust and long-term stable. All these advantages facilitate high performance optoelectronic devices, such as organic solar cells, hyperbolic metamaterials, plasmonic waveguides, etc. The second part is the research into metamaterials for light property manipulation. Metamaterials are artificially designed materials that enjoy extraordinary optical properties and have the potential to replace conventional bulky optical systems. Nano-size metamaterials are demonstrated for optical spectrum filtering (structured color filter) and polarization/direction control (asymmetric transmission and polarization conversion metasurface).
In-situ TEM on catalysts at atmospheric pressure with a novel gas cell technique

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The ability to monitor dynamic material transformation processes in-situ is crucial for understanding structure-property relationships in nano-engineered materials. In the past decade, most of the in-situ gas reaction results were acquired with a dedicated Environmental TEM (ETEM) where the pressure in the sample area is typically around 10 Torr. To make the in-situ condition more realistic, especially in terms of gas pressure, to mimic reactions in real life, a MEMS-based closed cell technique has been developed recently. Here we report results from utilizing this breakthrough technique to observe structural transformation in atomic scale in different material systems. In the first example, a recently reported novel catalytic material with exceptional methane combustion property is used to demonstrate how in-situ experiment can be used to link the structure-property relationship. Our results reveal that a wholly unexpected transformation occurs upon air calcination at temperatures between 500 and 800 °C, leading to the formation of a new structure comprised of an intimate mixture of palladium, cerium, silicon, and oxygen, with extremely high dispersion, and alternative explanation for the exceptional catalytic properties has been proposed. In the second example, a widely used three-way catalyst consisting size selected platinum NPs supported on high-surface-area alumina is used to demonstrate how in-situ observation can be used to explore coarsening mechanism of real catalyst under working condition, and provide helpful guideline for industrial application. Further improvement of the gas cell setup and new applications are still under development.
Wax deposition is a crucial operational challenge to the oil and gas industry. As early as in 1928, wax deposition was reported as a “one of the most troublesome problems in the production of crude oils”. During the late 20th century, the problem of wax deposition has become increasingly challenging, as the production of petroleum fluids shifted from onshore resources towards offshore reservoirs across the world. Wax deposition in subsea pipelines poses severe risks to offshore oil production. In order to remediate wax deposition problems in subsea pipelines, pigging operation is routinely performed. During the pigging operation, an inspection gauge, also known as a “pig”, is launched at one end of the pipeline. The pig travels along the pipeline and scrape off the deposit from the inner wall as it moves. It should be noted that excessively frequent pigging operation generates significant financial burden. However, with insufficient pigging, the wax deposit can grow to too thick and too hard and impossible to remove by pigging, leading to abandonment of the flow-line. Consequently, determination of an optimal pigging frequency is crucial in the design of a safe and cost-efficient oil production system. Wax deposition and aging rates predicted by wax deposition models are usually employed to assist the determination of an optimal pigging frequency. This presentation showcases the cutting-edge algorithms developed to generate reliable predications of wax deposition rate in oil pipelines.
Abstracts – Afternoon Session
AEP: Applied Electromagnetics and Plasma Science
A new technique for designing scalable phased arrays

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A phased array is an ensemble of antennas capable of beam forming and steering by adjusting the relative phase and amplitude of signals received or transmitted by each antenna element. Due to the spatial selectivity offered by phased arrays, they can reduce co-channel interference, multipath fading, and the required transmit power in telecommunication systems. Phased arrays are also able to enhance cross range resolution and signal to noise ratio in radar systems. Due to their aforementioned features, phased arrays are very attractive in commercial applications.

In conventional designs for phased arrays, there is one phase shifter per each antenna element. Phase shifters and their control circuitry highly impact the complexity, size, and cost of phased arrays. This research presents a new technique for designing phased arrays such that the required number of phase shifters is significantly reduced by integrating the phase shift function into the array's feed network.

As a proof of concept, a Ku band 8-element phased array utilizing only two phase shifters has been designed and fabricated based on the proposed method. The measurement results show 37 degrees of scan range.

From now on, the designed phased array antenna is being integrated to be applied to automotive radar applications. So far, a phase shifter is integrated using the IBM 130nm CMOS process. This phase shifter operates over the band 23-25GHz, and it is being utilized in the phased array system supposed to operate with the center frequency of 24GHz (as required by short range radars in automotive industry).
Towards the Analytical Design of Tensor Metasurfaces

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In this work, the sheet impedance tensors of patterned metallic claddings used in metasurfaces are found analytically. In the homogeneous (metamaterial) limit, simple expressions are derived under normal and oblique incidence for the sheet impedances of two separate topologies: skewed and three-branch unit cells. Variations of these geometries are also examined. The analysis allows the tensorial electrical surface properties to be directly related to realizable geometries. The analytical results are compared to those of full-wave simulations, and close agreement is observed. The models are then used to implement two different cascaded metasurfaces: an asymmetric linear polarized and a polarization rotator, both operating at 10 GHz.
Compact, Low-Power, Low-VHF Radios for Enhanced Networking in Complex Environments

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Reliable tactical networking in highly cluttered environments such as indoor and urban scenarios is a very challenging task that requires innovative and unconventional networking capabilities. Recent studies, which are based on physics-based modeling and simulation and extensive measurements, show that the lower VHF band has favorable propagation characteristics in such scenarios including minimal small scale fading and very small signal attenuation and distortion caused by dense scatterers compared to conventional microwave frequency bands. Despite these advantages at this frequency band, the realization of a compact, wireless and mobile communication system is challenging mostly owing to the large desired antenna size, or high power operation due to the poor efficiency of existing small antennas. To overcome such difficulty, we have recently developed reasonably efficient miniature antennas. In conjunction with them, the lower VHF band can be exploited for applications such as low power persistent one-hop communications and network node localization in complex scenarios. In order to enable experimentation with small autonomous platforms such as robotic rovers and flyers, ZigBee-based, compact, low-cost, low-VHF radios are designed and fabricated along with a highly miniaturized antenna. Performance tests on the in-house developed radios are conducted at various indoor/outdoor scenarios and the results are compared with those obtained from commercial ZigBee modules operating at the microwave frequency range in the same conditions. Utilizing miniaturized low-VHF radios, we have currently been working on multi-node networking for collaborative sensing and mapping with autonomous agents. Details of the radio design and measurements will be presented at the symposium.
A Phase-tunable, Liquid Crystal-based, Metamaterial Sub-reflector

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The sub-reflector presented operates at 90 GHz with less than 2dB of loss at the operating frequency while maintaining 180° phase shift across 8 GHz bandwidth. This device was designed using an iterative method that extracts the equivalent circuit parameters from an Ansys HFSS simulation and compares the extracted values to an idealized L-C circuit. From this L-C circuit model, we predicted far field patterns of the full device using aperture field method. In addition, we calculated the necessary phasing for each unit cell given a desired far-field pattern and feed horn pattern using the Gerchberg-Saxton method.

The device was fabricated using standard microfabrication processes. The sub-reflector consists of two 4” wafers with an SU-8 spacer layer, which forms a cavity for liquid crystals. By applying a bias voltage at each unit cell across this liquid crystal layer, we are able to manipulate the phases of the individual unit cells within the sub-reflector. The bottom wafer is a reflowed glass-in-silicon wafer, containing an array of silicon pillars within the glass substrate. Atop each silicon pillar is a copper patch. The top wafer is a quartz wafer with a series of offset patches connected together with a series of bias lines. The SU-8 spacer layer is 10μm thick, creating a liquid crystal filling of 6μm between the two sets of patches. This thin spacing should allow for fast liquid crystal switching speeds and fast configurability of the sub-reflector.
Simulation of Magnetic Nozzle Plasma Rockets

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Magnetic nozzles are strong magnetic fields that guide the flow of plasma in electrode-less plasma thrusters. Thrust is generated by magnetic nozzles through the interaction between the magnetic field and the expanding plasma. These magnetic nozzles also limit interaction between the hot plasma and the walls of the thruster thereby increasing lifetime. The plasmadynamics in a magnetic nozzle is complex and many magnetic nozzle devices of interest operate in regimes in which the physics may not be well described by conventional continuum models. Therefore, a novel quasi-one-dimensional particle-in-cell code has been developed to study magnetic nozzle physics by treating the plasma as a collection of particles.

The code resolves a single spatial dimension along the axis of symmetry and three velocity dimensions. Two-dimensional effects are modeled by including magnetic field forces and varying the simulation cross-section according to the conservation of magnetic flux. Validation simulations of single particle motion and magnetic mirrors were performed. Initial simulations of a device similar to the helicon double layer thruster were performed. These simulations showed that ion acceleration occurred due to magnetic field forces which push electrons out of the device. The electrons then drag the ions out with them, creating a beam of high energy ions necessary for efficient thrust production.
Time-resolved ion velocity distribution measurements near the hollow cathode of a Hall thruster

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Laser Induced Fluorescence (LIF) is a technique that can be used to measure ion velocity distribution functions in low temperature plasmas. Historically, this technique has been used to determine the acceleration potential in Hall thrusters. Recently, however, the combination of LIF with transfer function averaging has opened the possibility of making time-resolved LIF measurements. This new technique can be used to study oscillations in plasmas. Presented are preliminary measurements of near-cathode ion velocity distributions using time-resolved LIF. Two velocity distributions were measured in a LaB₆ hollow cathode plume under the influence of a Hall thruster magnetic field provided by the 6-kW H6 thruster. The discharge was sustained without a downstream anode but rather using the cathode’s heater and keeper. A third time-resolved velocity distribution was measured at the cathode exit in the full Hall thruster discharge under nominal magnetic field conditions.
Wireless Power Transfer with Non-diffracting Beams

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The generation of ideal propagating Bessel beams is typically limited to optical frequencies with bulky experimental setups, with analysis restricted to scalar wave theory. Recent work has shown that Bessel beam generation is possible at RF frequencies utilizing low-profile, planar, leaky-wave antennae. These previous studies assumed a single leaky mode in the antenna. In this work, the rigorous analysis of a planar Bessel beam launcher supporting many modes is presented. By employing mode-matching techniques to discontinuities in the feed, a complete solution of the structure and its supported modes is acquired. This thorough approach enables complete characterization of the Bessel modes supported by the structure, in addition to the free-space spectrum. Additionally, the planar Bessel launcher is analyzed in a coupled system, and it is shown that the structure can both transmit and receive Bessel beams. The energy transfer characteristics of the coupled system are analyzed, and the system's transfer power capabilities are discussed. An analysis of the coupled system's even and odd modes of operation show that efficient power transfer is possible, and an odd mode is preferred, as this yields high field confinement and power transfer.
Data-cubes of Vegetated Surfaces for Active Algorithm of SMAP: Model Development, Validation and Retrieval

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Different scattering models are developed for the L-band radar remote sensing of the vegetated surfaces. The models were used to compute data-cubes which are lookup tables of backscattering as a function of rms heights, vegetation water content (VWC) and soil moisture, for the NASA's Soil Moisture Active Passive (SMAP) mission. The wheat and canola data-cubes were based on the distorted Born approximation derived from the Foldy-Lax equation with the use of T matrix and half space Green’s function, which is labeled as incoherent addition of scattering amplitudes. However, it is found that for the soybean field, the incoherent models do not account for the magnitudes or the polarization ratios of the radar backscattering data. We used an improved coherent branching model by taking into account the correlated scattering among scatterers, where novel feature consists of conditional probability functions to eliminate the overlapping effects of branches in the former branching models. For crops such as corn, the VWC increases during a season, so that the optical thickness increases and multiple scattering effects should be considered. The multiple scattering effects were accounted for by solving the radiative transfer equation using an iterative approach. The surface scattering was determined by numerical solutions of Maxwell Equations in 3 dimensional simulations (NMM3D) for random rough surface scattering. The data-cubes have been validated and applied to the time series retrieval of soil moisture, resulting in RMSE (root-mean-squared error) as low as 0.05 m\textsuperscript{3}/m\textsuperscript{3} compared with the data from Soil Moisture Active Passive Validation Experiment 2012 (SMAPVEX12).
Model Validation for Plasma Contactor Mediation of Electron Beam Charged Spacecraft

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A high power electron beam can be fired from a spacecraft in the magnetosphere to trace the Earth’s magnetic field lines. However, the density of the ambient plasma in this region is too sparse to maintain spacecraft neutrality while the electron beam is operating. PIC simulations suggest that the spacecraft can be neutralized by using a hollow cathode to produce a dense, ion emitting plasma which balances the beam’s electron emission. [1,2] Here we present the results from a series of experiments which were performed at the Large Vacuum Test Facility (LVTF). These experiments were geared towards validating the PIC simulations and improving our understanding of the plasma-spacecraft interactions in this environment.
Simulating proton radiographs of Weibel-like magnetic fields

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In experiments studying the Weibel instability, proton radiography is used to image the magnetic filaments produced by the instability. Proton radiography is a useful technique for imaging the electric and magnetic fields in a plasma, yet inferring the 3D field structure from a 2D image presents a number of difficulties. We created a tool to perform numerical simulations of proton radiographs for 3D field structures with variable proton energies, source size, and orientation. Simulations were performed for multiple Weibel-like magnetic field configurations to determine the parameters responsible for the appearance of filaments on the radiograph. Of particular interest was how the number of and spacing between filaments in the image changes when changing the field structure. We observe that the ratio of the filament radius $a$ to the average inter-filament spacing $d$ is a main indicator of the number of filaments in the image, finding that as $a/d$ decreases, the number of filaments in the radiograph increases.
A novel microwave radiometric technique, wideband autocorrelation radiometry (WiBAR), offers a deterministic method of remotely sensing the propagation time $T_{\text{delay}}$ of microwaves through low loss layers at the bottom of the atmosphere. Terrestrial examples are the snow and lake ice packs. This technique is based on the Planck radiation from the surface beneath the pack which travels upwards through the pack towards the radiometer; such a signal we call a direct signal. On the other hand, part of this radiation reflects back from the pack’s upper interface then from its lower interface, before traveling towards the radiometer’s antenna. Thus, there are two signals received by the radiometer, the direct signal and a delayed copy of it. The microwave propagation time $T_{\text{delay}}$ through the pack yields a measure of its vertical extent. We report a time series of measurements of the ice pack on Lake Superior from February to April 2014 to demonstrate this technique. The observations are done at frequencies from 7 to 10 GHz. At these frequencies, the volume and surface scattering are small in the ice pack. This technique is inherently low-power since there is no transmitter as opposed to active remote sensing techniques. The results of this paper is to present the WiBAR technique and show that the microwave travel time within a dry snow pack and lake ice pack can be deterministically measured for different thicknesses using this technique.
The Time Evolution of Streamer Discharges in Single and Multiple Bubbles in Water

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The interaction of plasma with liquid water lies at the heart of a variety of revisited technological applications ranging from water treatment to wound healing. Plasma ignition and propagation in water, however, is poorly understood. It has been theorized that plasma streamer propagation takes place in microbubbles, namely streamer bubble hopping. In this work, discharge development in single and multiple bubble acoustic systems is investigated using high-speed imaging and emission spectroscopy. Optical filters allow for time resolved measurements of specific chemical species as well. Better understanding of these breakdown processes will guide the construction of an effective plasma water purifier.
Generating Arbitrary Radiation Patterns With Metasurfaces

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Metasurfaces have demonstrated tremendous control of electromagnetic wavefronts. Incident electromagnetic beams can be refracted using these textured surfaces with zero reflection. A topology of cascaded electric sheet admittances has also been employed to provide extreme polarization control.

However, unless partial reflections are intentionally introduced, these metasurfaces do not offer control over the transmitted amplitude. Here, control of transmitted wave amplitude without loss of energy to reflected waves is explored using leaky-wave antennas (LWAs). A leaky-wave antenna can be designed by placing a partially-reflecting surface (PRS) atop a ground plane. Here, the PRS employed is a metasurface. Through inhomogeneity, the magnitude of the transmitted wavefront can be controlled, in addition to the phase and polarization.

It will be shown that by spatially varying the parameters of the proposed metasurface, arbitrary wavefronts can be generated. Previous demonstrations of arbitrary pattern synthesis did not include polarization control. Moreover, previous structures employed vias, whereas a planar, layered design is used here, which is simpler to fabricate. In this presentation, these capabilities are briefly discussed and demonstrated using full-wave simulation.
All-directions through the wall radar imaging using a limited number of moving transceivers

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Through the wall radar imaging is used for mapping buildings’ interiors and detecting static or moving objects behind the walls. This technique has found many applications in rescue and search operations. Current approaches for through the wall radar imaging employ UWB radars with large arrays of antennas to achieve high resolution. Due to the limited space, placing large antenna arrays inside the buildings is not practical in the most cases and as a result, current methods usually perform imaging from outside of the buildings. These systems can usually investigate the first floor of the buildings and their imaging capability decreases as the complexity of the building interior increases. This research introduces a new method for all-directions through the wall radar imaging. In the proposed method, instead of using large antenna arrays, a limited number of transceivers mounted on moving robots are used. As robots move, reflected signal is sampled at different positions. By applying an appropriate beam forming technique to the samples of the received signal, a 360° view of the building interior can be obtained with a high cross-range resolution. To evaluate the performance of the proposed method, the first floor of EECS building (as a complex and large three-dimensional structure) is simulated and imaged by the method and results show the performance of the method in imaging of complex structures. A radar system that is realizing the proposed imaging method is also designed and fabricated.
High Q BST based Switchable Thin Film Bulk Acoustic Resonators and their Application as an IR Resonant Sensor

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The aim of this project is the design, characterization, and fabrication of high Q acoustic resonators based on Barium Strontium Titanate (BST) for high sensitivity IR resonant sensors. As a result, compact and high sensitivity IR sensor arrays could be utilized for low cost and large-scale commercial applications.

Ferroelectric materials with the composition of $\text{Ba}_x\text{Sr}_{(1-x)}\text{TiO}_3$, which have been utilized for tunable varactors, possess field induced piezoelectricity (electrostriction). BST based switchable Bulk Acoustic wave (BAW) resonators have been recently demonstrated. Without externally applied bias voltage these resonators act as simple capacitors; with the application of DC bias voltage, due to electrostrictive effect of the BST, the effective piezoelectric constant become non-zero and increase with the magnitude of applied voltage, therefore, a resonance appears in the impedance response of the resonator. Switchable and tunable acoustic filters based on BST Thin Film Bulk Acoustic Resonators (FBARs) have been reported recently. High quality BST based resonators will improve the performance the proposed switchable filters as well.
CDR: Control, Dynamics and Robotics
Reduced-order Models of Bladed Disks with Friction Ring Dampers

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An efficient methodology to predict the nonlinear response of bladed disks with a dry friction ring damper is proposed. Designing frictional interfaces for bladed disks systems is an important means adopted to dissipate vibration energy. Placement of dry friction dampers between blades or under the blades is a widely used technique. One of the recently emerging technologies uses ring dampers. These are ring-like substructures constrained to move inside a groove at the root of the blades. Such rings are in contact with the bladed disk due to centrifugal forces, and they create nonlinear dissipation by relative motion between the ring and the disk. The analysis of dynamic response of multiple degrees of freedom nonlinear structures is commonly derived by numerical integration of the equation of motion which is computationally inefficient especially for steady-state responses. To address this issue, reduced order models (ROMs) are developed to capture the nonlinear behavior due to contact friction. The approach is based on expressing the nonlinear force as equivalent damping and stiffness. Pre-calculations of the response-dependent equivalent terms contribute the increase of the computational speed of the iterative solution method. A sector level model, including the bladed disk and the damper, is used to demonstrate the method. Macro- and micro-slip models are used in the friction model to account for realistic behavior of dry friction damping. For validation, responses due to steady-state traveling wave excitations are examined. Results computed by ROMs are compared with results from transient dynamic analysis (TDA) in ANSYS with the full order model.
Dynamic Modeling, Trajectory Optimization, and Control of a Flexible Kiteplane

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This work investigates dynamic modeling, trajectory optimization, and control of a flexible kiteplane used for wind-energy harvesting. The individual components of the kiteplane, including flexible wings and a rigid fuselage, are modeled separately and then constrained together using the null-space method. The flexible wings of the kiteplane are modeled as flexible plates, and the Rayleigh-Ritz method is used to discretize the partial differential equation that describes the strain energy stored in the wing. The attitude of the kiteplane is described by the direction cosine matrix (DCM) directly and a proportional-integral-derivative (PID) control law that makes use of the DCM is implemented for attitude control. An unsteady aerodynamic model based on Theodorsen's lift model is used in simulation to allow for an accurate model under transient conditions. A suboptimal trajectory is proposed, along with an optimal trajectory found using a simplified dynamic model and solving a finite-dimensional constrained optimization problem. Numerical simulations of the suboptimal and optimal trajectories are performed to demonstrate the kiteplane's energy-harvesting capability.
Constrained Control for Landing on an Asteroid with Model Uncertainty

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An autonomous control strategy is developed that enables soft landing of a spacecraft on a small rotating asteroid using a constant density ellipsoid gravity model. A disturbance canceling input observer is used to compensate for the error between the estimated and actual gravity model. An extended command governor is used to enforce constraints on control and landing speed while performing collision avoidance. The spacecraft landing mission is divided into two phases. A circumnavigating phase places an ellipsoidal constraint around the asteroid that guarantees collision avoidance while bounding control. A landing phase keeps the spacecraft within a pyramid that tapers near the landing point while reducing speed as it approaches the surface. A simulation is performed on the full nonlinear model with actual gravity parameters demonstrate successful landing using the proposed controller scheme.
Optimal Defense Policies for Partially Observable Spreading Processes on Bayesian Attack Graphs

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The defense of computer networks from intruders is becoming a problem of great importance as networks and devices become increasingly connected. We develop an automated approach to defending a network against continuous attacks from intruders. The approach uses the notion of Bayesian attack graphs to describe how attackers exploit system vulnerabilities in order to penetrate a network. We assume that the attacker follows a probabilistic spreading process on the attack graph and that the defender can only partially observe the attacker’s capabilities at any given time. This leads to the formulation of the defender’s problem as a partially observable Markov decision process (POMDP). We define and compute optimal defender countermeasure policies, which describe the optimal countermeasure action to deploy given the current information.
Measuring Human Interest during Technical Poster Presentations

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Individual and situational factors influence human interest during conversation, and this level of interest is manifested in non-verbal behaviors. Social robots, or robots that can interact with humans on a conversational level, are used mainly to teach humans or give humans directions. The more comfortable a human feels with a social robot, the more effective an interaction it will be, and interest in a conversation will increase this level of comfort. We have designed an experiment to measure and increase human interest during a type of conversation, with the goal of increasing the overall effectiveness of the conversation. We have set up a simulated technical poster presentation, in which the human listens to technical posters presented by a robotic avatar. The human’s body posture and eye gaze are measured, and the content of the poster presentation is changed based on observation. Using a Wizard of Oz method to control the presenter, our goal is to measure the interest of the human and attempt to increase the level of interest among the various posters. We have performed our experiment on 19 users and have observed a statistically significant increase in interest when the presenter adapts to the non-verbal behaviors of the human. This research has several applications, most notably in the realm of tour guide robots. If a robot giving a tour of a museum is able to adapt to the interests of humans touring the museum, humans will learn more overall and thus have a more effective conversation with the robot.
Real-Time Hybrid Simulation of Manufacturing Systems for Performance Analysis and Control

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Simulation is a common way to analyze the performance of a manufacturing system. This study can be done at different levels. On a system level, entities are modeled based on production and failure rates using Discrete Event Simulation (DES). On a machine level, the Continuous Dynamics (CD) of machines are studied based on position, velocity, and acceleration. However, these models are usually run separately, losing key information that could be used for more accurate control of the system performance. In this paper, we merge DES and CD in a single hybrid simulation environment for a more detailed system analysis. By synchronizing the simulations to run in real-time, the results can be compared with information from the plant floor. We match the data from the real world performance metrics to close the gap between the virtual and real environments. The data from both simulation and plant floor are stored in separate databases and then compared. Using the simulation outcome as a reference, any significant deviation of the plant floor performance would represent an error and would trigger an event that can be automated or inform an operator of a required action. We discuss the implementation of a hybrid simulation in a fully automated manufacturing system, with CNC machines, conveyors, and robots. In addition to the system throughput, we simulate the dynamics of the robots and monitor their joint positions. The results are evaluated within confidence intervals to validate the approach.
Distributed Reactive Control Protocol Synthesis for Aircraft Electric Power Systems via SAT Solving

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This work considers co-synthesis of distributed control architectures and correct-by-construction control protocols for aircraft electric power systems. We start with a single line diagram of the electric power system circuit topology and a global assume-guarantee contract, where the assumptions capture possible internal and external events (e.g., failures of system components, or pilot commands, respectively), and guarantees capture safety requirements for the system. We compute a distributed control architecture that maps sense and control points to individual local controllers. This is accomplished by representing the power flow constraints on the circuit with a graph and by localizing the strongly connected components of this graph. By construction, the resulting architecture consists of subsystems over which there is a partial order. We show that by using this partial order, computation of local assume-guarantee contracts for each subsystem on this architecture can be reduced to a sequence of satisfiability modulo theory problems. The control protocols for local controllers can then be separately synthesized. Moreover, implementing these local control protocols together guarantees the satisfaction of the global contract. The efficacy of the proposed method is demonstrated on a large-scale aircraft electric power system topology, representative of those in next generation more electric aircrafts.
Improving Teleoperation Performance with Semi-Autonomous Behaviors

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Teleoperation is a crucial operation mode for robots in tasks ranging from search and rescue to surgery. However, teleoperation of robotic assets in distant environments is plagued with difficulties including communication latency and poor perception of the robot’s environment. This project has explored how communication latency impacts human operator performance when driving ground robots. To mitigate the effect of communication latency on performance, a new model predictive control based semi-autonomous behavior has been developed. The method shares control of the robot between a human teleoperator and an autonomous controller. The method is applied to a human sharing control with an obstacle avoidance controller while navigating a wheeled mobile robot. Results from a human subject study (N=20) demonstrate performance (e.g. average speed, number of collisions) improves and that communication latency has less of an impact on performance with the new semi-autonomous behavior. The new semi-autonomous control method is computationally efficient and has potential applications in a variety of areas including search and rescue, reconnaissance, and telepresence systems.
Feedback Control during Mode Transition for a Marine Dual Fuel Engine

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Mode transition is an important control challenge for dual fuel engines, particularly for marine applications where fuel quality and composition may vary over a wide range. Feedback control is critical for dealing with fuel uncertainties and assuring robust performance. In this paper, a model-based approach is pursued for dual fuel engine mode switch control. A mean-value control-oriented model for a marine dual fuel engine is constructed in MATLAB/Simulink environment. This model is used to emulate the mode transition process for shipboard generator set applications. Three different control architectures are examined for feedback control based on engine speed regulation during mode transitions. Based on the metric that reflects engine speed tracking error, it is found that a Multiple Input Single Output (MISO) architecture with feedback corrections applied to both gas fuel and diesel is advantageous versus architectures that apply corrections to only one (either diesel or gas) fuel command.
Synthesis of Robust Switching Protocols for Vehicle Engine Thermal Management

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Thermal management is very important to guarantee ideal performance of the compact vehicle engines. One challenge in the vehicle engine thermal management is to control the engine temperature in a small interval while tolerating the uncertainties in complex environment and different operating conditions. We formulate this control problem as a “reach and stay” problem of a switched affine system and solve it by synthesizing a switching protocol based on an abstraction, i.e., a graph obtained from the model to capture its “high-level” dynamical behavior. The vertices of the graph are abstracted from partitioned subsets of the state space, and the edges from the dynamics of the model. In order to capture all possible dynamical behavior of the model, it is usually inevitable to introduce additional undesired behavior (nondeterminism) in the abstraction, which makes it harder to synthesize a controller. Besides, most of the existing algorithms for computing abstractions cannot handle parametric uncertainties in the dynamics. Main contribution of this work are (i) to show under the assumption that the vector fields are multi-affine in constant uncertainties and affine in state variables (which is true for our car engine thermal model), how to compute an abstraction based on polytopic subsets, and (ii) how to obtain successively better abstractions with less nondeterminism by splitting these subsets properly.
Optimizing Motion and Morphology: The Effect of Series and Parallel Elasticity on a Two-Dimensional Hopper

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The way that a legged system is built and the way that it moves are inherently coupled. In order to move in an energetically efficient way, a robot must take advantage of its natural dynamics, which will depend on its physical structure. Building the best possible legged robot for a particular purpose is then a fundamentally difficult problem. We must simultaneously optimize the motion and morphology in order to compare the best possible versions of robots. To develop a systematic methodology for this type of comparison, we look at the effect of series and parallel elastic actuators on the motion of a two-dimensional hopper. This hopper contains springs in both the hip and the leg which are connected either in series or parallel to motors. As we have shown in our previous work on a one-dimensional hopper, these different actuators lead to fundamentally different motion. In two dimensions, there are four possible actuator combinations. In simulation, we optimize a robot with each of these combinations for three different measures of energy usage as a function of forward velocity. These optimizations include motor parameters and spring values as free parameters. We don’t simply compare a particular implementation of leg and hip actuators, but rather, compare the optimal robots with each implementation against each other. This work not only seeks to answer the question of optimal spring configuration, which is a source of open debate in the robotic community, but also, explores the effect of morphology on the energetic cost of motion.
Property Enforcement for Partially-Observed Discrete-Event Systems

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The problem under consideration in this presentation is that of enforcement of a given property on a partially-observed discrete-event system. We present a general methodology that is applicable to a large class of properties previously studied (individually) in the literature. These properties include, but are not restricted to, safety, diagnosability, opacity, detectability, anonymity and attractability. Our uniform approach first maps the considered property to a suitably-defined information state for the partially-observed system and then develops a supervisor (or sensor activation) synthesis methodology based on a finite bipartite transition system that embeds all reachable information states and all admissible supervisory control (or sensing) strategies. We illustrate the application of our uniform approach to the enforcement of the above-mentioned properties.
CEE: Civil and Environmental Engineering
Thermo-mechanical Shell Elements and Coupled Fire-Structure Simulations

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“Traveling fires” have become an emerging trend in the field of structural fire engineering for the last several years. A fire receives the *traveling* label when it initiates in one region of a building and spreads throughout its compartment and possibly into surrounding rooms. Recent high-profile cases of damage caused by this type of fire scenario have led to an increased awareness and interest in preventing such disasters. With the attention of the research community on cases such as the collapse of the World Trade Center Towers in New York City (2001) and the post-fire demolition of the Windsor Tower in Madrid (2005), a major focus in recent publications has been the development of novel methods for simulating the structural response to natural fire scenarios, including future consideration for traveling fires.

The current study presents an efficient simulation framework for modeling thin-walled structures exposed to stationary, localized fires. Here, a thermo-mechanical shell element was developed based on a heat transfer shell with temperature degrees of freedom (Jeffers, 2014) and traditional shell theory for the membrane and bending capabilities (Yunus et al., 1989). The element was enhanced with the capability to receive non-uniform thermal boundary conditions from fire simulation software, based on computational fluid dynamics, to characterize the natural fire behavior in the structure model. Subsequent coupled temperature-displacement analyses for the structural response were performed using the finite element method. A major consideration in this fire-structure simulation framework was the efficient transfer of temporal and spatial data from the fire model to the structure model.
Effect of Shear Stud Layout on the Behavior of Reinforced Concrete Slab-Column Connections under Gravity Loading

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Headed shear studs are often used in reinforced concrete slab-column connections as shear reinforcement. In North America, shear stud rails are normally placed perpendicularly to column faces in a so-called orthogonal (or cruciform) layout to reduce interferences with slab flexural reinforcement. Thus, as opposed to connections with stud rails in a radial layout, a large region of the slab-column connection may be unreinforced in shear when a cruciform layout is used. Some research has shown the absence of radial stud rails in an orthogonal layout could lead to premature punching shear failures at slab-column connections. This presentation discusses an experimental program aimed at studying the effect of shear stud layout, radial or orthogonal, on the behavior and failure mode of reinforced concrete slab-column connections. A total of five full-scale interior slab-column connections were monotonically loaded to failure. Slabs were 10 ft by 10 ft and 10 in. thick, and columns were 12 in. by 12 in. The specimens were built with Grade 60 reinforcement and 4000 psi normal weight concrete. The flexural tension reinforcement ratios were approximately 0.8\% in three slabs and 1.2\% in the other two. One specimen that had a reinforcement ratio of 0.8\% was built without shear reinforcement, while the other specimens were reinforced with the same amount of headed shear studs. Test results showed some significant differences in the behavior and failure of slab-column connections with shear studs arranged in radial and orthogonal layouts.
Development of a Finite Element Model for Reliability Assessment of a Long-span Railroad Truss Bridge Exposed to Multi-Hazards

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The United States rail industry is reliant on the use of many historic bridges located throughout the national rail network. Many of these bridges are exposed to multi-hazards which consist of two or more hazard scenarios. This study focuses on a risk assessment of the Harahan Bridge in Memphis, TN which is a 100 years old steel truss bridge that is exposed to seismic and vehicular impact. To perform a risk assessment, the study primarily focuses on the development of a high-fidelity finite element (FE) model of the Harahan Bridge. The FE model has been constructed to simulate various damage scenarios, and has enabled the team to validate an optimal sensing strategy and instrumentation plan based on the results of the model’s structural analyses and bridge responses due to various dead, live, and dynamic moving load cases. The model is used to assess the load effect on key structural elements so that the reliability of each structural component can be assessed and quantified. The study also investigates the ideal instrumentation strategy for the bridge.
A Parallel Execution of Adaptive Structural Control in Dual-Core Wireless Sensor Networks

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Structural control systems have been proven effective in minimizing the response of civil engineering structures to earthquakes, typhoons and other extreme events. The design of traditional feedback control systems is dependent on the assumption of the structure being linear time invariant. This assumption may be violated during extreme loads due to system nonlinearity and the introduction of damage. In this study, a recursive system identification strategy is implemented to continuously track the system properties of a dynamic structure. Concurrently, an optimal feedback control law is found based on the varying system model generated by the system identification module. To implement system identification and control law derivation concurrently, a flexible controller infrastructure is required. Towards this end, the study utilizes the low-power, dual-core Martlet wireless sensors developed at the University of Michigan. The wireless platform executes online system identification recursively on one core while derivation of an optimal control law based on linear quadratic regulation (LQR) theory is implemented on a second core. By parallelizing the implementation of the LQR control law and system identification, the wireless sensing network is shown to be capable of learning and adapting to system changes in real-time. Simulation and experiments on a 4-story benchmark shear structure is utilized to show the validity and scalability of the proposed adaptive feedback control approach.
Subspace System Identification Method for Vehicular Load Estimation using Vehicle-bridge Monitoring System

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The dynamic vehicular load is a dominant factor which leads to the aging and deterioration of highway bridges over their life cycles. While significant work has been done on vehicle-bridge interaction (VBI) theoretically, less attention has been paid to experimentally capturing the dynamic loads imposed on bridges by heavy trucks. This study introduces a comprehensive wireless monitoring system that seamlessly integrates a mobile wireless sensor network installed in a tractor-trailer truck to measure dynamic truck behavior with a stationary wireless monitoring system installed on a bridge to measure bridge vibrations and strains. A mathematical VBI model, which can well predict bridge responses, is first estimated using a proposed two-stage subspace system identification method from time-synchronized truck-bridge responses. To extract dynamic vehicle axle loads backwards from measured bridge responses, a gray-box system with physically meaningful configuration is then derived based upon the identified model. The Telegraph Road Bridge (TRB) in Monroe, Michigan is used as a validation platform.
Assessing the State of Michigan’s Water Withdrawal Assessment Tool in Evaluating High Volume Groundwater Withdrawal

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Excessive and unsustainable water resource and groundwater withdrawal is a growing issue in the Great Lakes region, leading to the formation of the Great Lakes Compact. The State of Michigan developed the Water Withdrawal Assessment Tool (WWAT) as a screening tool to evaluate any high volume groundwater withdrawal (>1000 gal/day) related to agricultural, industrial and industrial activities within the state. However, recent developments in hydraulic fracturing have created additional pressure to the groundwater resources in the form of high-volume short term withdrawal and the WWAT is still used to assess such pumping. In this study, we are using MODFLOW, a finite-difference groundwater numerical model to evaluate if the WWAT can accurately assess hydraulic fracturing associated water withdrawal and how it is compared with those of agricultural water withdrawals. We found that for short-term high volume groundwater withdrawal, WWAT’s assumption of 5-year pumping period and aquifer properties provide a conservative approach to the calculation of the stream depletion. However, we found that the analytical solution used by the WWAT has the potential to underestimate the stream depletion. The same analysis will be conducted to see if the WWAT can accurately assess agricultural related water withdrawals. The outcome of this study will provide information for water resource manager for future development in science based sustainable water policy.
A Novel Method to Determine Fatigue Life of Naval Vessels

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Current procedures for predicting fatigue life of naval vessels and their components involve heavy reliance on complicated finite element models, thus presenting the need for a more efficient method. Towards this end data collected from a low-cost, non-intrusive wireless monitoring system temporarily installed on a United States Coast Guard (USCG) 45’ RB-M were analyzed to relate the ship’s response to sea conditions. The vessel was tested over the course of four days in heavy weather environments and acceleration, strain and displacement data were collected. To understand the relationship between these data and the external conditions, the ship speed and wave height from the captain’s log and calculated heading were considered. The captain’s log was compared to National Data Buoy Center (NDBC) data to verify the wave heights. These conditions were then categorized according to wave height, ship speed and heading to understand the data, particularly acceleration and strain. In order to calculate the heading, the pitch and roll were calculated using four methods all based on acceleration data. Strain data was converted to stress cycles and counted using a rainflow algorithm then an S-N curve was determined in order to use Miner’s Rule to calculate the vessel’s consumed fatigue during the field test. The next step is to extract simulated acceleration time series or spectra from POWERSEA based on known sea conditions, then to correlate this to the collected data. The acceleration data can then be correlated to the actual consumed fatigue as compared to simulated fatigue.
Monitoring and Control of Indoor Building Air Quality using Mechanical and Natural Ventilation

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In US, building sector accounts for 41 percent of the national energy use, and 80 percent of this energy is consumed during operation phase. To address this growing problem, technical approaches such as improving insulation, using efficient equipment, intelligent controls, night-time ventilation have been discussed in existing literatures. However, due to relatively high initial costs, uncertain energy reduction potential and low taxes and energy prices, the feasibility of these technical measures has come into question.

As opposed to technical measures, occupants’ behavior also draws researchers’ attention because of low cost, large participation and applicability in both new and old buildings. Azar and Menassa investigated the impact of nine occupant-related actions on energy consumption of commercial buildings in 10 different weather climates, and found out that the combined effects of some actions resulted in a more than 50% increase in energy use. Masoso and Grobler conducted six energy audits in commercial buildings in Botswana and South Africa and concluded that 56% of energy was used during non-working hours. Peschiera et al. studied occupant’s peer network in a residential building and observed significant energy reduction when occupants were exposed to their peer network utilization information.

In this research, we first developed an application which provides occupants with information about current indoor/outdoor condition, historical and future weather data, comfort temperature range, recommendation on the window state, and energy savings if using natural ventilation. Then, a survey was carried out to study occupant’s response as well as the effectiveness of our application.
Vision-based Automated Action and Posture Analysis of Construction Workers

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Understanding workers’ actions and postures is essential for human safety, health, productivity monitoring in construction. Even though video recording can be used for automate data collection for action and posture analysis, tedious manual review consumes significant time to obtain worker action and posture information. In this project, an effective and efficient computer vision-based action and posture recognition approach is proposed, especially for detecting unsafe actions and non-ergonomic postures in videos. Time information is a critical factor in assessing workers’ ergonomic risk, productivity etc. Accordingly, in contrast to currently prevalent action recognition methods that assume only one action occur in each video clip, our approach recognizes different actions/postures shown in the video on a frame-by-frame basis. This essentially gives our method the strength to further conduct time and frequency analysis of each action/posture. The temporal information provided has significant advantage of high accuracy over manual estimation, and thus gives it a strong strength in specific assessment of ergonomics, productivity, etc. The proposed method is preliminarily tested in lab setting, and the result shows great potential to be applied in the real jobsite. In addition, our project is currently developing a mobile app oriented system incorporating mobile phone as client, remote server, database etc. Through the system the user could utilize his/her cell phone to collect video data and to input user information, leaving data processing to remote servers without requiring from user any technical knowledge about the algorithm or even software installation and maintenance in personal computer. The overall automated system demonstrated certain potential for specific on-site human worker monitoring application in construction.
Electromechanical Development of a Low-Cost End Effector Pose Estimation System for Articulated Excavators

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Vision-based pose estimation, in which optical cameras monitor fiducial markers to determine the three-dimensional positioning and orientation of an articulated machine’s end effector, offers a promising low-cost alternative to currently available sensor packages that are non-ubiquitous and cost prohibitive for a large portion of the market. Whereas traditional sensor systems determine end effector pose via kinematic chains passing through the links of a machine, optical sensor systems are capable of determining pose by observing an end effector directly. However, since markers cannot be mounted on an excavator’s bucket for occlusion and durability reasons, a short kinematic chain must be used. An electromechanical design is proposed to provide such function for a low cost marker-based excavator pose estimation system. Several iterations of design and experimental evaluation are discussed, including a four-bar linkage system, a synchronous belt system, a bucket linkage system, and a cable potentiometer system. The four-bar linkage and toothed belt systems were designed to transmit bucket angle information to cameras through the manipulation of a marker’s pose, but were found to possess Gimbal lock and practicality issues, respectively. To overcome such issues, a generalized mapping approach was adopted and implemented in a bucket linkage design and a cable potentiometer design. The viability of the cable potentiometer system was experimentally confirmed, along with the identification of further work needed to refine the technology for large-scale practical implementation.
Real-time Building Energy and Comfort Parameter Monitoring Using Autonomous Indoor Robots

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Buildings contribute to more than 40% of the primary energy consumption in the US. This number is rapidly growing every year and thus there is a strong need to reduce the energy consumption in buildings. Studies show that, monitoring and collecting energy related data in real-time will help identify the energy wastage, improve energy efficiency of buildings, and maintain occupants comfort. Traditionally, such data has been collected in buildings using wired or wireless systems by installing a dense array of sensors at floor and room level. This is an effort and cost-prohibitive approach, especially in existing older buildings where instrumentation and integration with existing building systems is challenging. This study develops a novel concept of using autonomous mobile indoor robots for monitoring various occupant comfort and energy parameters inside an existing building, and discusses how the collected data can be utilized in various analyses. The research evaluates the hypothesis that a single multi-sensor fused robotic data mule that collects building energy, systems performance, and occupancy comfort data at sparse locations inside a building can provide decision-makers with a rich data set that is comparable in fidelity to data obtained from pre-installed and fixed sensor systems. In order to demonstrate the effectiveness of the proposed approach, an experiment was conducted using an autonomous robot (with sparse set of sensors). The data collected by the mobile robot was statistically compared with data obtained from the building’s pre-installed Building Automation System. Experimental results demonstrated the method’s applicability in collecting dense actionable data in large spaces using only a sparse set of sensors mounted on mobile indoor robots.
Finite Element Analysis of Steel-Concrete Composite Floor Systems under Traveling Fire Conditions

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This paper presents a computational investigation aimed at better understanding the global structural behavior of steel-concrete composite (SCC) structures subjected to single-story horizontally traveling fires. Using the traveling fires methodology (TFM), a range of spatially and time-varying fire exposures are applied to a three-dimensional (3D) finite element (FE) macro model of a SCC floor system designed following US design standards and practices. The sequentially coupled thermal-mechanical (dynamic) simulations were carried out using commercially available finite element modeling package ABAQUS, where the structural modeling approach was verified using experimental test data from the Cardington fire test. Analysis results indicate that structural response during a traveling fire is dominated by longitudinal differential thermal expansion (DTE) in the composite floor system, which induces asymmetrical responses in the structural system. Such asymmetrical responses can potentially lead to thermally-induced actions not accounted for in conventional structural fire engineering design codes, namely significant load redistributions, differential torsional effects on spandrel edge beams, and induced torsional effects on columns, among other things. Furthermore, DTE has the potential to effect the mobilization of tensile membrane action (TMA) in partially insulated composite floor systems in large open-plan compartments, and thus can influence the passive fire protection scheme chosen for the subsequent steel floor beams. The effects of DTE are briefly characterized using FE results and a strong case is presented for the inclusion of DTE in the analysis and design of structures in fire.
Two-Step Design Method for Engineered Geopolymer Composite

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The first version of Engineered Geopolymer Composite (EGC) was developed at the University of Michigan. EGC is a family of strain-hardening fiber-reinforced composites for resilient and sustainable infrastructure applications. EGC exhibits tensile strain-hardening behavior with high ductility of over 3% which is several hundred times that of normal concrete. In the strain-hardening stage, multiple cracking occurs with tightly controlled crack width (less than 50 microns). Due to the unique tensile properties, EGC can be regarded as a type of “bendable concrete”. In addition, unlike other concrete materials in which cement is the primary ingredient, EGC matrix consists of geopolymer that is a new type of binder materials produced from industrial byproducts. Therefore, EGC is a promising sustainable construction material. However, the first version of EGC possesses low compressive strength which might limit the range of EGC applications. While matrix modification is required to increase the strength, design of geopolymer (and fiber-reinforced concrete) has often been conducted by trial-and-error approaches. This study presents a systematic design methodology for fiber-reinforced geopolymer composites. The design process includes two-step optimization for matrix and composite development. In the first optimization, the statistical Design of Experiment (DOE) is employed to modify the geopolymer matrix. Then, the micromechanics-based design is used in the second optimization to find optimal fiber and fiber/matrix interface properties (i.e. composite design). A new version of EGC developed based on the integrated design method possesses compressive strength of over 40 MPa while maintaining the tensile strain-hardening characteristic, high ductility, and tight crack width.
Designing a Facility to Improve Pedestrian Safety in Ethiopia

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The WHO predicts that roadway fatalities will be the 5th most common cause of death by 2030. In Addis Ababa, Ethiopia, 87% of road user deaths are pedestrians. During the summer of 2015, design ethnography techniques were used to identify unmet pedestrian safety needs at 27 intersections in Addis Ababa and a single need, providing crossing facilities for atypical and disabled pedestrians, was pursued as part of a design internship program. Numerous conceptual solutions were generated and a raised crosswalk positioned on a speed table was selected as the most effective facility given the lack of power required and its ability to modify driver behavior by giving right of way to pedestrians crossing the road. Preliminary analyses suggest that this method has the potential to be effective in improving pedestrian safety in congested low-resource settings without significantly affecting traffic flow.
What Can Seashells Teach Us About Designing Durable, Resilient Building Materials for Sustainable Infrastructure?

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Taking cues from nature’s mollusk shells, a cementitious composite has been designed to provide concrete infrastructure with improved durability and resilience. Despite being composed 95\% of brittle calcium carbonate, nacre (the iridescent material seen inside mollusk shells) exhibits high tensile strength, tensile ductility, and toughness. Concrete, like the calcium carbonate material nacre is made from, is brittle and weak in tension, leading to cracking failures observed frequently, even under normal loading and environmental conditions. By adapting nacre’s hierarchical composite design to a larger scale and to a strain-hardening cementitious system, we aim to achieve a combination of mechanical properties never before seen in cementitious materials. Adding tensile strength and tensile ductility to the already impressive compressive strength of concrete can provide a much more durable material, useful for reducing repairs and extending service life of infrastructure under normal loading conditions, and providing enhanced safety in extreme conditions like natural disasters, impacts, and blasts. The nacre-inspired composite also includes an autogenous self-healing mechanism, providing a resilience woefully absent in most infrastructural materials. The constraints of civil infrastructure (processing speed, ease, cost, etc.) have guided the composite development to ensure real-world feasibility and broad impact. The experimental investigation has focused thus far on verifying the contribution of salient features of nacre in generating the specific deformation mechanisms responsible for nacre’s remarkable mechanical performance on a size scale larger than in nacre.
User-Guided Dimensional Analysis of Indoor Scenes Using Depth Sensors

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In many civil engineering tasks, dimensional analysis of environmental objects is significant for spatial analysis and decision-making. Tasks such as as-built geometry generation need to efficiently interpret the critical dimensions of specific objects (e.g., diameter of a pipe, width of an opening) in a potentially cluttered environment based on data gathered from different positions. This paper presents a user-guided dimensional analysis approach to automatically acquire geometric information from a single frame of a depth sensor. Firstly, a depth sensor is used to capture three-dimensional (3D) point clouds of indoor scenes. Then by extracting planes and performing geometric analysis, the dimensional information of objects of interest is obtained from a single frame. Our user guidance system evaluates the quality of the current data and measurement and provides interactive guidance for moving the sensor to acquire higher quality data, from which more accurate geometric measurements can be obtained. The proposed method has been tested on hallways, door frames and stairs. The experimental results demonstrate that the method offers significant promise in enabling accurate dimensional analysis in a wide variety of civil engineering measurement contexts.
Long-term Modal Analysis and Condition Assessment of a Wirelessly Monitored Wind Turbine

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With the development of wind energy, wind farms have been constructed increasingly onshore and offshore around the world today. The operation and maintenance (O&M) cost of the wind turbines is comparatively high due to the large structure size, the remote location (offshore) of the wind farms, the cost of component replacement and so on. A lot of researches have been focusing on condition monitoring and damage detections of wind turbines in order to reduce the O&M cost. A good understanding of the dynamic structural response of the wind turbine is preliminarily needed for condition monitoring and detections. This study focuses on developing methods for assessing the structural performance of a 3 kW wind turbine system. A short-term wireless monitoring system was installed along the steel tower of the turbine to collect the acceleration response of the tower under varying environmental and operational conditions. An automated modal parameter routine is implemented to identify tower structural modes. Damage in the wind turbine tower is identified using stochastic model updating schemes.
Determining Ice Pressure Distribution on Ice-force Measuring System (IFMS) Panel using Orthotropic Plate Inverse Theory

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Inverse algorithms are presented to calculate the variable pressure acting on a stiffened steel plate. The analytical models are formulated to calculate the quasi-static pressure distribution caused by ice and wave loads. The loading pressure is calculated using strain measurements from a stiffened plate installed on a Keweenaw Peninsula lighthouse in Lake Superior. Both strip beam theory and orthotropic plate theory are applied to obtain the linear relation between pressure terms and strain values. In the inverse plate theory, we seek the Fourier pressure terms as calculated output from the strain values measured on the plate stiffeners.

Two approaches are employed using orthotropic plate theory: the first model presumes the pressure acts over the entire plate; the second model presumes the pressure to act only over the depth of the ice thickness. Favorable comparisons are made of results determined from orthotropic plate theory to results determined from finite element analysis. Both approaches are shown to provide results in agreement with the finite element analyses. The peak pressures determined from the field measurements using the inverse orthotropic plate theories are in the range of 1.3 to 3.5 MPa for the local pressures, and 0.7 to 3.0 MPa for the average pressures acting over the entire plate. A demonstration using the recorded data for experiments exhibits the effectiveness of the presented approach.
MTR: Medicine and Translational Research
Nanodroplet Mediated Histotripsy Validation on 3D Prostate Cancer Models

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Focal therapy approaches have limitations on high-volume and multi-modal tumor lesions, and the success of focal prostate cancer therapy depends on the ability to selectively ablate cancer lesions. To address current therapeutic limitations, we developed nanodroplets (average diameter<500nm) encapsulating perfluorocarbons(PFC), which can rapidly expand in <1µsecond when exposed to therapeutic ultrasound and mechanically fractionate neighboring cells with the significantly reduced cavitation threshold. To test the tumor ablation efficiency of the different PFCs(PFP or PFH)-encapsulated nanodroplets, we developed 3D-prostate cancer spheroids from PC-3 and C4-2B cancer cells. First the spheroids were treated with NDs upon exposure to histotripsy(9.0 MPa), more than 60% of the cells of both PC-3 and C4-2B spheroids were killed with PFP/PFH loaded nanodroplets comparing to w/o PFP/PFH-loaded nanodroplets low-pressure ultrasound signal(10 MPa) according to resazurin viability assay. Further, we developed agarose 3D tumor phantom model that mimicked the cells inside a tissue extracellular-matrix. The applied treatment groups were no ND with low-pressure(13 MPa), no ND with high-pressure(28 MPa), with PFP-loaded NDs with low-pressure (13 MPa), and with PFH-loaded NDs with low-pressure(13 MPa). After the treatments, the ablated area of the spheroids was calculated. No nanodroplets low-pressure could ablate less than 20% area for both cell lines. However, no nanodroplets with high-pressure ablated around 80% of the spheroids. Whereas, with low-pressure, PFP-nanodroplets destroyed 40% of the spheroids, and PFH-nanodroplets could ablate almost 80% of the spheroids. These results indicate PFC-loaded nanodroplets significantly reduce the histotripsy threshold, and PFH-loaded nanodroplets with low-pressure can destroy the cells as efficient as high-pressure.
Side-viewing Confocal Endomicroscope for In Vivo Imaging

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Colorectal cancer is a leading cause of cancer-related deaths in the United States, despite the widespread availability of colonoscopy. By using cancer targeting molecular agents and high resolution imaging, it is possible to capture the molecular changes in the colon in the early stage of cancer. Confocal microscopy is a powerful tool to perform high resolution imaging of biological tissues. However, it is challenging to scale down a tabletop microscope into an endoscope but remain its performance, and the small field of view makes it hard to find the location of the lesion during in vivo imaging. Here we introduce a side-viewing confocal endomicroscope with 4.2 mm outer diameter and subcellular resolution for panoramic imaging of the mouse colon. Near infrared laser centered at 660 nm is delivered through a single mode fiber into the endomicroscope. The light is collimated and focused by miniature lenses. The focused beam is reflected 90 degrees by a 2D resonant MEMS mirror into a tissue contacting lens. The probe is mounted onto a rotational and translational mechanism, such that the whole distal colon can be imaged in order to create a panoramic view with cellular resolution. For in vivo experiments, fluorescence-labelled peptide was injected intravenously in to genetically engineered mice with colonic dysplasia. We demonstrate in vivo imaging of colonic dysplasia in mice with histology-like imaging performance. Our instrument can be potentially translated into the clinic for colon cancer screening.
Noninvasive Ultrasonic Transcranial Brain Therapy Using Histotripsy

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Hemorrhagic stroke can lead to the formation of large clots within the brain, causing direct and indirect damage to the brain, leading to significant neurological impairment. Surgical evacuation remains the mainstay therapy for hemorrhagic stroke but hasn't proven beneficial, as surgical traversal of the brain often leads to additional damage. Minimally invasive techniques using thrombolytic drugs have seen success, but require excessive treatment times (3-7 days) and don't significantly improve outcomes. Current state-of-the-art research uses magnetic resonance guided focused ultrasound (MRgFUS) to noninvasively liquify clots through the skull and catheters to drain the liquid. MRgFUS has reduced treatment times (e.g., ~40mL in ~3hrs), however, unwanted skull heating limits MRgFUS's ability to treat clots larger than 40mL or within 2cm of the skull. Histotripsy is a noninvasive focused ultrasound therapy that can liquify clots larger than 40mL and closer to the skull, up to 10-fold faster than MRgFUS. Using short duration (~2 acoustic cycles), high-amplitude ultrasound pulses histotripsy generates cavitation microbubbles within the clots that act to mechanically fractionate/liquefy them while minimizing skull heating. In this study, histotripsy was used to liquify large volume (80mL) clots through three excised human skullcaps using a 500kHz, 256-element hemispherical histotripsy transducer. Through each skullcap 6 clots were treated. Initial results show liquefaction rates up to 2mL/min without significant skull heating, an order of magnitude faster than MRgFUS. Results demonstrate histotripsy as a novel technique to significantly improve hemorrhagic stroke treatment. Further research is needed for optimization, safety investigations and in-vivo feasibility.
Dental Caries Diagnosis with Fluorescent Bio-based Nanoparticles

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We have developed a fluorescent bio-based nanoparticle which targets early forming dental caries, so that they can be illuminated and identified using a dental curing light commonly used in dental offices. Nanoparticles were prepared and analyzed physically and chemically, prior to testing effectiveness at illuminating cavity lesions on human teeth. Computer image analysis to select light specific to the particles’ fluorescence further improved the contrast, suggesting that computer-aided diagnosis is possible. Furthermore, 2-photon microscopy images demonstrate the specificity of the particles and provide insight into the architecture of early cavity lesions. The bio-based chemistry makes the particles non-toxic, degradable by salivary amylase, and inexpensive to produce. This novel diagnostic could be used in-line with current dental practices to assist dentists in the diagnosis of carious lesions.
Fiberless Multicolor Optoelectrodes For Neural Circuit Analysis

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The existing optogenetic engineering tools available to study and manipulate brain networks come with limited functionality. We report design, fabrication, packaging and in vivo feasibility of a compact, minimally invasive, fiber-less, multicolor optoelectrode that can provide spatial precision and scalability needed to enable many novel experiments such as closed loop excitation and creation of synthetic patterns to study plasticity. The highly compact optical design is implemented using eutectic-bonded side-emitting injection laser diodes (ILD), coupled via gradient-index (GRIN) lenses, to 7µm thick and 30µm wide dielectric optical mixer waveguides on a 22µm thick Michigan probe. This novel waveguide approach provides independent activation and inhibition of simultaneously monitored neurons by illuminating different wavelengths at a given stimulation site and can be expanded to synchronously stimulate multiple optical sites along the shank length. The waveguide mixer design and alignment tolerances of optical assembly are thoroughly simulated in Zemax to maximize optical system efficiency. We have achieved 10 to 3000 mW/mm² of irradiance range at the waveguide tips during optical bench testing and have successfully validated device feasibility in mice models to show neuronal activation and inhibition with 405nm and 635nm wavelengths, respectively. Combined with varied color choices for manipulating multi-opsins expressing local neural populations, this multi-port mixer waveguide design also offers an effective thermal isolation between light sources and tissue, realizing modular implantable optoelectrode array. Such versatile optogenetic tools ultimately hold a potential for allowing neuroscientists to study complex brain networks and understand mysteries of brain disorders like Alzheimer's and Parkinson's.
Application of a Graphene Oxide Based Microfluidic Device (GO Chip) to Prostate Cancer Circulating Tumor Cell Capture and Analysis

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One in seven men in the United States will be diagnosed with prostate cancer in his life time, in part because of the prevalence of screening for serum levels of prostate specific antigen (PSA). However, this has led to the overtreatment of the disease, leading to recommendations against frequent PSA testing and establishing the need for a more informative biomarker in prostate cancer. Circulating tumor cells (CTCs) are rare cells present in the blood stream of cancer patients at the low frequency on the order of one CTC in one billion normal blood cells. The graphene oxide chip (GO Chip) is a microfluidic CTC capture device with increased sensitivity and purity due to its use of the nanomaterial graphene oxide to present a capture antibody against the epithelial cellular adhesion molecule (EpCAM). In this study, whole blood was collected from 45 prostate cancer patients with metastatic castrate resistant disease and analyzed using the GO Chip. Captured cells were either stained for cytokeratin, CD45, and DAPI, with nucleated cytokeratin positive cells being denoted as CTCs, or cocultured on-chip for further analysis. Correlation of CTCs with surrogate endpoints could improve the utility of CTCs as a liquid biopsy, potentially advancing their application in translational research while an expanded population of these highly relevant biomarkers could allow additional analysis for the guidance of therapeutic selection and the study of cancer biology.
Development of Targeted, Enzyme-Activated Nano-Conjugates for Hepatic Cancer Therapy

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Liver (i.e. hepatic) cancer is currently the 3rd leading cause of cancer-related deaths worldwide, and continues to lack an effective therapy. The current work involves developing a therapeutic drug delivery system targeted to hepatic cancer cells (HCC) that is able to release a loaded drug controllably within those cells. Specifically, a chemotherapeutic agent, doxorubicin (DOX), is conjugated to generation 5 (G5) polyamido-amine (PAMAM) dendrimers via different aromatic azo-linkers that exhibit a controllable release profile of DOX within HCC. We have previously shown that the display of N-acetylgalactosamine (NAcGal) ligands on G5 dendrimers through a poly(ethylene-glycol) (PEG) brush results in selective recognition and internalization of the nanoparticles into HCC via the highly expressed asialoglycoprotein receptor. We have also shown that the NAcGal-PEG-G5-L(x)-DOX nano-conjugates are able to selectively target and internalize into HCC, and that this internalization correlated with controllable cytotoxicity profiles comparable to the free drug. The present work quantifies the kinetics of drug release through detailed metabolomics and mass spectrometry studies, identifying the specific active moiety contributing to therapy. Further, we present the development of a tumor-bearing mouse model by ectopic implantation of HCC tumor cells in nude NSG mice. Using this model, we investigated the nano-conjugate’s therapeutic efficacy \textit{in vivo} through intratumoral administration. These results offer valuable mechanistic evidence and provide insight into the nano-conjugate’s potential as a novel drug delivery system that can be translated to the clinic for hepatic cancer therapy.
Microfluidic Study of Circulating Tumor Cells from Different Venous Sources in Early Lung Cancer

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Circulating tumor cells (CTCs) are cells shed by a tumor into the blood stream and are believed to be involved in the spread of cancer to other parts of the body. Their isolation from the blood can act as a blood biopsy, or a less invasive source of information about the disease. Lung tumor resections offer an opportunity to obtain blood from the pulmonary vein (PV) draining the tumor, which presumably has CTCs in higher abundance in comparison to the peripheral vein (Pe). Evaluating CTCs in early stages could be a useful method of early detection of cancers. However their rare frequency in the blood hinders their analysis. Microfluidic technologies are useful for studying CTCs, and antibodies targeting these cells can be used for capturing them. A high-throughput microfluidic device for CTC capture developed recently, the OncoBean Chip, was utilized to study CTCs from the different venous sources from early lung cancer patients. The captured CTCs were further characterized by genetic profiling. Studying CTCs in early lung cancers could potentially provide an insight into the disease progression and aid in early detection.
Regeneration of the Bone-Ligament Complex Using 3D Printed, Patterned Polymeric Substrates

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Macro-scale substrate topography is an important scaffold design parameter for \textit{in vitro} guidance of cellular alignment. In this study, we explore the potential of 3D-printed, micropatterned polycaprolactone (PCL) substrates to support mineralized and aligned soft tissue formation for the regeneration of the bone-ligament complex in the oral cavity. Patterns consisting of grooved and non-grooved pillars were embedded onto PCL films, and combined with a bulk 3D-printed PCL base for the bone region, then seeded with ligament progenitor cells or fibroblasts transduced with AdBMP-7, respectively. Analysis of samples indicates significant increases in cellular orientation, nuclear elongation, and thickness of oriented collagenous tissue at 6 weeks post-implantation relative to tissue formed on non-grooved pillars and randomly-oriented porous PCL. Presence of deeper grooves (30um) resulted in significantly greater cellular alignment relative to shallow grooves (10um), with groove depth overriding the effects of wider (60um) and narrower (15um) grooves. Analysis of bone formation using micro-CT showed increased bone tissue mineral density at 6 weeks compared to 3 weeks, with no significant changes in total bone volume. The results of this study confirm the importance of substrate topography for promoting aligned tissue formation \textit{in vivo} and the potential of a tissue engineering approach using combined 3D-printed, micropatterned scaffolds as platforms for regeneration of complex bone-ligament interfaces.
EMG-Based Weight Classification during a Symmetrical Lifting Task: A Pilot Study

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Back injury, due to lifting, is a leading cause of missed work days in the U.S. Current injury prevention approaches utilize passive lifting belts, which are biomechanically ineffective at unloading the lower-back. This introduces a need for robotic assistive devices that provide active support. The control of active devices requires effective human models that can identify a user’s intent to perform a task and allow the device to adapt accordingly. Models that are able to predict or identify the task at an early state enable faster and more responsive devices that will off-load the back muscles during the initial phases of the lifting cycle; thus, reducing the likelihood of injury. In this research, we investigate the use of a neural network model to identify the lifted weight during a repetitive lifting task in a single-subject pilot study. Leveraging the existence of anticipatory muscle activity as the subject prepares to lift a heavy weight; features of lower-back muscle activity signals are used as inputs to the neural network model. The model is used to classify the current loading condition from three possible cases: no weight, light (4-lbs), and heavy loading (24-lbs); during three time frames: prior to the initiation of weight lifting (Pre-onset), within 500ms of lifting (Early-onset), and after 1sec of lifting (Post-onset). The post-onset and early-onset models show similar classification performance, validating that early prediction is possible. The pre-onset model performs better than random guessing, indicating a potential for predictive weight classification; although this area requires further investigation.
Radiofrequency Pulse Design for MRI with Direct Constraint on Peak Pulse Amplitude

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Inhomogeneity in the main magnetic field ($B_0$) is a major concern in magnetic resonance imaging (MRI) where the induced off-resonance frequencies can lead to blurring or signal loss in medical images. For example, inhomogeneity at air-tissue interfaces in the human brain sinuses can create off-resonance bandwidths well exceeding 300Hz for a 2D slice. Many acquisition schemes have been proposed to correct field inhomogeneity by designing radiofrequency (RF) excitation pulses. Recent work designing pre-winding spectral RF pulses has been effective to recover off-resonance signal loss. Furthermore, larger bandwidth of off-resonance can be recovered when spatial variation of field inhomogeneity information is obtained and encoded within the RF pulse design as a spectral-spatial pulse. Nevertheless, designing purely spectral and spectral-spatial RF pulses is challenging—these RF pulses cannot exceed a short prescribed time duration, they cannot surpass peak amplitude values dictated by the RF amplifier, and they cannot deposit power above human safety limits. For pre-winding pulses, the limiting design factor has primarily been the pulse peak amplitude. Since pulse design is formulated as a weighted least squares optimization problem, peak amplitude was indirectly controlled through heuristically tuning the Tikhonov regularization parameter. Resulting pulses do not always meet the same amplitude, making performance comparisons across pulse designs challenging. This work introduces an optimization method that designs spectral and spectral-spatial pulses with direct constraints on peak amplitude. This method establishes peak amplitude requirements without parameter tuning and without adding significant computation time. Furthermore, pulses designed match or improve previous pulse design methods.
Photoacoustic In Vivo Imaging of Hepatocellular Carcinoma with EGFR-Targeting Peptide

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Worldwide, hepatocellular carcinoma (HCC) is the second most lethal cancer, causing 745,000 deaths annually, with a 5-year survival of < 5\%. Molecular imaging provides a more accurate and specific detection of early lesions and tumor. Cell surface targets offer easy accessibility and fast binding kinetics. Up to 47\% of HCCs express the membrane target, epidermal growth factor receptor (EGFR), most likely contributing to the aggressive growth characteristics of HCC. Photoacoustic imaging with near-infrared (NIR) fluorescent probe enables deep (~1 cm) tissue penetration and superior contrast. In this preclinical study, a NIR dye (Cy5.5) labeled 7-mer peptide was used as a molecular probe that demonstrated high affinity (K\textsubscript{d} = 50 nM) for EGFR binding \textit{in vitro}. Nude mice bearing HCC xenograft tumor (diameter 6.5 ± 2.1 mm, n=8) were injected 250 uL 300 uM Cy5.5-labeled target and control peptide probes systemically respectively. PA imaging revealed detailed vasculature around the tumor (imaging depth = 8.1 ± 1.3 mm). The labeled peptide demonstrated maximum contrast at 3 hours in a time course from 0 to 24 hrs. In the same tumors from the same mice, the T/B ratio at tumor was significantly greater than that for the scrambled control peptide 2.26 ± 0.59 versus 1.48 ± 0.39, P = 0.02 by paired t-test. \textit{In vivo} imaging via photoacoustic tomography with NIR-labeled peptide offers a simple, effective and rapid technique for noninvasive \textit{in vivo} monitoring and quantitative analysis of HCC tumor growth and EGFR expression.
NRS: Nuclear Engineering and Radiological Sciences
CFD-Grade Experiments of Thermal Striping in Nuclear Reactor Coolant Branch Lines and CFD Validation

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Thermal fatigue is a mechanism that leads to cracking in pipes which branch from nuclear reactor primary coolant piping and are primarily dead-ended. This phenomenon is a pressing issue for light water reactors, as well as advanced reactors cooled by liquid salts or metals. The main flow (hot) creates a secondary flow swirl which propagates in the branch line (cold). In the branch line below where the flow swirl transitions from turbulent to laminar, thermal stratification occurs. The interaction of the hot flow swirl and this stratified layer causes the hot and cold boundary to fluctuate, inducing thermal fatigue in the branch line walls. Predicting the fluctuations of the hot and cold boundary by means of analytic/empirical models has historically proven to be challenging, due to the complexity of the involved fluid dynamic interactions. At the same time, the assessment of the predictive capabilities of high fidelity computational fluid dynamics (CFD) methodologies (such as Large Eddy Simulations) has been hindered by the lack of sufficiently detailed experimental data. The present project will produce a database of CFD-grade experimental data characterized by high spatial and time resolution providing:

a) greater physical insight into the fluid-dynamic phenomena responsible for inducing thermal fatigue in branch lines;
b) sound basis for the validation of associated CFD models;
c) enhanced predictive capabilities of structural analysis codes used to analyze crack propagation;
d) greater design efficiency and lower failure probability of reactor piping.
A coupling infrastructure code, *Janus*, has been developed at the University of Michigan, providing methods for the online data transfer between the commercial CFD code STAR-CCM+ and the best-estimate thermal hydraulic system code TRACE, developed by the US NRC. Coupling between these two software packages is motivated by the desire to extend the range of applicability of TRACE to scenarios in which local momentum transfer and three-dimensional effects are important, such as circulation through an open region. The intra-fluid shear forces neglected by TRACE equations of motion are readily calculated in CFD solutions. Consequently, the coupling methods used in this study are built around correcting TRACE solutions based on data from a corresponding STAR-CCM+ solution. Two coupling strategies are discussed, one based on an overlapping domain approach and a second based on separate domains. These coupling methods have been applied to the simulation of open and closed loops in both steady state and transient operation. The objective of this study is to examine the effect of each coupling method on convergence, consistency, and numerical stability. As expected, the results produced by the two methods were found to be identical, and consistent with the standalone TRACE solution in both steady state and transient cases. However, the overlapping domain method was found to achieve convergence at larger integration time steps than the separate domain approach and exhibited superior convergence and numerical stability characteristics in both steady state and transient scenarios.
Active Interrogation of plasma-liquid boundary using 2D plasma-in-liquid apparatus

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Plasma medicine and plasma-based water purification technologies rely on production and transport of plasma-derived (direct or indirect) reaction species into the bulk medium. This interaction takes place at the interface between the gas phase plasma and the liquid medium. The nature of radical production and subsequent radical transport from this region or boundary layer is not well-understood due to the difficulty of implementing diagnostics to interrogate this region. We present a 2-D plasma-in-liquid water apparatus that makes the interface region accessible to optical diagnostics. Using colorimetric chemical probes, acidification and oxidation fronts are tracked using high-speed imaging and spectroscopy. Additionally, observed, plasma-induced fluid dynamical effects are also discussed. Forces at the interface can play a key role in the transport of radicals into the bulk solution. Effects on bacterial viability are discussed.
Dielectric barrier discharge (DBD) treatment of tissue has been shown to improve the healing of difficult-to-heal wounds and is being investigated for cancer treatment. Typically a wound or other biological sample is covered in a thin liquid layer of serum. As a result, the interactions between the plasma and the liquid are central to this type of medical treatment. Though wound healing has been observed, the mechanism of the therapeutic effects is not well understood. One possible mechanism involves reactive species (ions and neutrals) solvating in the liquid, and eventually interacting with the tissue underneath. Reactive species of interest often include ozone, oxygen atoms, hydroxyl radicals, nitrous oxide, HNO\textsubscript{x} and N\textsubscript{x}O\textsubscript{y}. In this paper, we discuss results from a computational investigation of the plasma chemistry in the gas and the liquid layer as a function of the pulse repetition frequency and gas residence time. A 0-D plasma kinetics model, GlobalKin, couples the gas and liquid chemistry using Henry’s Law for solvation of gases into water. GlobalKin is much less computationally demanding than spatially resolved models, which enables the investigation of a more complete chemistry and longer timescales. With this capability, carbon dioxide, sulfates and biomolecules can also be included in the analysis, in addition to the standard humid air chemistry.
Development of Biomechanical Models to Describe Dose-Volume Response to Liver Stereotactic Body Radiation Therapy (SBRT) Patients

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Previous studies have shown that radiation therapy treatment for liver metastases causes marked liver hypertrophy (growth) in low dose regions and atrophy/fibrosis (shrinkage) in high dose regions. This work develops a biomechanical model-based dose-response model to describe volumetric and spatial response of the liver to stereotactic body radiation therapy (SBRT) treatment. Dose-based boundary conditions were applied to a biomechanical model-based deformable registration algorithm, Morfeus. Finite element models were created with liver/tumor contours on planning and post-RT CT/MR images. A thermal expansion-based relationship correlating the delivered dose and volume response was generated from 10 patients previously treated. This coefficient and the planned dose were applied as a boundary condition describing liver volumetric response of metastatic liver patients treated with SBRT. The accuracy was evaluated based on overall volumetric liver comparisons and target registration error (TRE) using average deviations in positions of vascular bifurcations on each set of registered images, with a target accuracy of 2.5mm isotropic dose grid. Results show that the thermal expansion coefficient models liver volumetric changes within 3%. A TRE of 5.9±2.3mm using Morfeus with dose-boundary conditions was yielded compared to 8.3±3.2mm using rigid registration and 7.0 ±2.3mm using Morfeus with only spatial boundary conditions. A biomechanical model has been developed to describe the volumetric and spatial response of the liver to SBRT. This work will improve correlating functional imaging with delivered dose, mapping delivered dose from one treatment onto planning images for a subsequent treatment, and will assist with biologically characterizing patients’ response to radiation.
High Resolution Experiments of Velocity and Concentration Fluctuations in a Jet Flow

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We present a novel experimental technique aimed at the simultaneous measurement of velocity and scalar fluctuations with high spatial and time resolution. Measurements have been performed using wire-mesh sensors in combination with Stereo Particle Image Velocimetry (SPIV) to achieve synchronized measurements of both velocity and scalar fluctuations, and therefore of the turbulent fluxes $u'_j\varphi'$. The proof-of-concept of this measurement technique was obtained on a jet flow experimental facility HiRJet (High Resolution Jet) developed and built in ECMF laboratory at the University of Michigan. Acquired experimental data indicates a high temporal resolution of proposed technique and capabilities of achieving a high level of synchronization which is confirmed by cross-correlation between wire-mesh and SPIV signals.
Application of the Method of Manufactured Solutions to Sn Equation in Planar Geometry

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Method of Manufactured Solutions (MMS) is one of the numerous most rigorous computer code verification methods for the correctness of numerical algorithm and software implementation. It has great flexibility in verifying all functionalities of a computer code and has seen wide applications in many engineering fields. However, limited application is seen in neutron transport field, especially in eigenvalue problems. This is partially due to the high dimensionality of the Boltzmann Transport Equation and the error introduction, propagation and interaction caused by various approximations. In this work, applicability in neutron transport code is investigated and demonstrated. A set of three problems are devised to cover problems with and without scattering source, external source, anisotropy or analytical solution. Ideas of isolation and removal of errors from certain approximations are proposed and shown in the example of removing error from angular approximation when assessing the convergence with spatial resolution. Additionally, methodology of applying MMS to eigenvalue problems is developed. The way of normalizing the initial guess in the eigenvalue calculation proves effective in verifying an eigensolver, in which both $k$ and cell-average scalar flux show the same order of accuracy as the finite difference method in the grid refinement of a certain phase space. The procedure and methodology developed are demonstrated in planar geometry Sn equations and prove effective.
A Multi-level Quasi-Static Kinetics Method for Pin-Resolved Transport Transient Reactor Analysis

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Three-dimensional, full core transport modeling with pin-resolved detail for reactor dynamic simulation is important for some multiphysics reactor applications. However, it can be computationally intensive due to the difficulty in maintaining accuracy while minimizing the number of time steps. An innovative Predictor-Corrector Quasi-Static Method (PCQM) is introduced which is based on a Transient Multi-Level (TML) methodology. Two level of couplings are used between 3D-Transport/3D-CMFD (Coarse Mesh Finite Difference) and 3D-CMFD/EPKE (Exact Point Kinetics Equations). In each level, the original flux equation is solved in the coarse predictor step and then is factorized as an amplitude and a shape function in the corrector step, where the predicted solution is adjusted using multiple fine steps. In the first level 3D-Transport/3D-CMFD coupling, the angular and sub-pin flux shape function in the Boltzmann transport equation assume to vary slowly over time and the CMFD cell wise amplitude function is solved using multiple steps by 3D-CMFD transient equation. In the second level, the CMFD scalar flux calculated in the last step is further corrected by a whole core wise amplitude function generated by EPKE solver. The utilization of hierarchical multi-level neutronics transient solvers achieves the goal to balance the numerical accuracy and computational efficiency. In addition, a new iteration scheme with pin-resolve Thermal-hydraulics feedback and theoretical proof for the accuracy of PCQM are also presented. Finally, a stripe assembly case adopted from the SPERT transient tests is used to demonstrate the accuracy and efficiency of the TML method.
OPS: Optics, Photonics, and Solid-State Devices
Dynamic Terahertz Switch Comprising Cylindrical Spoof Surface Plasmon Polariton Waveguide

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This work demonstrates a terahertz (THz) switch that partially comprises a metallic perfect conductor in the form of periodically corrugated cylindrical waveguide surrounding a dielectric medium made of GaAs compound semiconductor. Propagation of spoof surface plasmon polariton along a periodically corrugated cylindrical waveguide has been investigated. It has been demonstrated that the propagation of SSPP signals can be controlled by modulating the refractive index of the dielectric material. At resonant frequency it supports strong electromagnetic confinement inside the resonating grooves. The complete switch uses the Waveguide-Cavity-Waveguide (WCW) structure and controls the state of the switch by dynamically altering the optical properties of the material located inside the cavity while waveguides are used for propagation of electromagnetic waves only. The cavity has high quality factor and can trap electromagnetic waves for significant period of time. Then, small changes in the GaAs refractive index inside the grooves can change the cavity resonant frequency. It is shown that by implementing localized doping near the metal conductor inside the cavities, applying voltage to the metal electrode, and depleting the free charges in the dielectric directly underneath the contact, the structure can switch between the on-state and the off-state. The proposed idea can be implemented in THz circuitry and Boolean gates.
Hybrid Memristor/CMOS Integration with 3D Vertical Structure

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Hybrid CMOS/nanodevice (“CMOL”) integrated circuits combines the merits of dominating CMOS technology with molecular-scale nanodevices, which can provide high defect tolerance, together with high performance and extremely high density. Integration of memristive devices with CMOL interface is well suitable for large scale memory storage and neuromorphic computing systems. However, the limitation of lithography resolution confines memristor device scalability. With 3D vertical structure, one dimension of the active device is determined by the thickness of the deposition rather than lithography, which further increases storage density. In this work, we demonstrated the integration of dual-layer vertical WO\textsubscript{x} based memristive devices with CMOL interface by fabricating memristive devices directly on a 5x5 mm\textsuperscript{2} custom designed foundry-CMOS chip, with two identical Pt/WO\textsubscript{x}/W memristor devices formed on one side of the sidewall. Some single cells were also fabricated to demonstrated the similar electrical characteristics of the upper and lower layer devices.
Vertical Ge/Si Core/Shell Nanowire Junctionless Transistor

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Vertical junctionless transistors based on Ge/Si core/shell nanowires epitaxially grown and integrated on heavily doped <111> Si substrate were fabricated and analyzed. Due to the high density one-dimensional hole gas formed in the Ge nanowire core, P-type transistor behavior with \( I_{on} \) of 923 \( \mu \)A/\( \mu \)m and subthreshold swing of 125 mV/dec was obtained. A numerical model based on full depletion approximation was developed and good agreement was reached between simulation and measurement data with minimal fitting parameters. Devices with two different gate lengths were fabricated by tuning the thickness of PMMA as etching mask and their performance were evaluated. Single pronounced peak was observed on the histogram of ON/OFF current difference of both devices, indicating good uniformity and high confidence of single nanowire operation. In addition, using two vertical nanowire junctionless transistors, a PMOS-logic inverter with near rail-to-rail output voltage was demonstrated. We have shown that junctionless transistor based on vertical Ge/Si core/shell nanowire can be fabricated in a controlled fashion with good yield, and all measurement data can be understood and explained by theoretical model.
Measurement of Charge Balance and its Effect on Electrophosphorescent OLED Lifetime

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Reliability is an important problem for the success of commercial deployment of phosphorescent organic light-emitting diodes (PHOLED). PHOLED degradation can be attributed to multiple pathways, including the loss of charge balance, molecular degradation due to high energy bi-molecular recombination reactions, and delamination. We present studies on the contribution of charge balance to degradation of high efficiency PHOLEDs. We employ a charge balance sensing technique that allows direct measurement of charge imbalance. This technique involves introducing a sensing molecule which causes exciton leakage to manifest as light which is spectrally resolved from the device emission with high efficiency. We use this technique to probe charge and exciton leakage from the emissive layer as a function of current density and degradation time. The measured charge balance together with luminance loss, voltage rise, and time resolved external quantum efficiency characteristics are used as input to a physical model describing degradation of PHOLEDs. Finally, the efficacy of electron / exciton blocking layers over the device lifetime is examined.
A flexible thin-film InGaAs photodiode focal plane array

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Natural imaging systems such as the retina and the compound eye employ a conformal architecture that provides an aberration-free image with wide field of view (FOV) and very low f/number. However, most artificial imagers such as conventional cameras are limited to a planar architecture demanded by the use of brittle semiconductor focal plane arrays (FPAs). High resolution image formation on this flat field requires multiple bulky optical elements. Here we demonstrate a high performance FPAs on flexible and/or conformable substrates that can be shaped to overcome these fundamental limitations. An 8×100, lightweight, thin-film In\textsubscript{0.53}Ga\textsubscript{0.47}As p-i-n photodiode FPA with sensitivity to wavelengths as long as 1650 nm is fabricated on a thin flexible plastic foil following transfer by adhesive-free bonding of the epitaxial layers that are subsequently lifted off from the parent InP substrate. The array is shaped into either a convex cylindrically curved imager to achieve a 2\pi FOV, or when formed into a concave shape, to provide high resolution and compact spectral decomposition over a wide wavelength range. The array exhibits \textasciitilde99\% fabrication yield with \textasciitilde100\% peak external quantum efficiency at 1300 nm. The unique features of this flexible thin-film FPA provide a new paradigm for realizing advanced electronic and imaging applications.
Ternary Alloys of Rare Earth Scandates as Solution-processed High-k Dielectrics

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Here we report dielectric properties of spin-coated rare earth scandates \((Y_xSc_{1-x})_2O_3\), demonstrating their feasibility as high-k dielectrics for low-cost large-area electronics. Rare earth oxides are mechanically-strong, thermodynamically-stable materials with large optical bandgaps (> 5eV). For electronics, they can be used as high-k dielectrics due to large ionic polarization and large band offsets to many semiconductors. Higher-order alloys of rare earth oxides may be preferable over binary oxides due to better thermal stability against crystallization [1,2] and better moisture resistance [3], and are typically deposited by vacuum techniques [1-3]. Here, thin films of yttrium scandium oxide \((Y_xSc_{1-x})_2O_3\) were deposited by spin-coating and annealing at 500°C [4]. Capacitors were formed by top metal contact deposition. The ink alloy fraction \(x (x=[Y]/([Y]+[Sc]))\) varied from 0% to 100%. Electrical properties of the capacitors were obtained using impedance spectroscopy from 100 Hz to 100kHz. All films show good dielectric behavior. The relative dielectric constant monotonically decreases with the Y atomic fraction \(x\), from 22.1 to 7.5. DC current-voltage measurements showed that all films have a low leakage current of \(10^{-8}\)A/cm² at ±2V and a high breakdown electric field of 4 MV/cm. Grazing angle X-ray diffraction shows the as-deposited \(Sc_2O_3\) and \(Y_2O_3\) films are both nanocrystalline, whereas the \((Y_{0.6}Sc_{0.4})_2O_3\) film doesn't crystallize until above 600°C. References: [1] Christen et al. Appl. Phys. Lett., 2006. [2] Myllymäki et al., J. Mater. Chem. 2010. [3] Zhao et al., Appl. Phys. Lett. 2010. [4] Hu et al., Electronic Materials Conference, 2015.
Organic conjugated polymers are promising materials due to its potential to be used for next generation optoelectronic devices. Especially, organic photodetectors (OPDs) allow new innovations such as flexible imager enabled by the ease of the manufacturing on the flexible substrates. Bulk heterojunction (BHJ) system is the most famous choice for the active layer in the OPD structure which can be prepared by the one-step deposition of a polymer : fullerene blend solution. However, co-existence of the electron acceptor and donor materials on both anode / cathode interface challenges the effective suppression of the dark injection current due to ill-defined schottky energy barriers. Substantial dark current suppression can be achieved, in principle, by controlling donor / acceptor vertical segregation employing the double-layered active layer on OPD. However, realization of the multilayered structures of polymer / fullerene active layer using solution process is challenging due to the difficulty of finding “orthogonal” solvents. In this work, we employ a novel double transfer stamping (DTS) method to realize the well-defined bilayer OPD. Further optimized annealing process of the bilayer device facilitates the interdiffusion of the fullerene molecules into the polymer to achieve extremely suppressed dark current and high photo-responsivity level at the same time. The fabricated OPD device exhibited extremely low dark current density of $9.83 \times 10^{-9}$ A/cm$^2$ and high responsivity value of 295 mA/W at 1.5V reverse bias. The specific detectivity in this work exhibited $5.25 \times 10^{12}$ Jones at 546nm wavelength.
Current progress in blue phosphorescent organic light-emitting diodes (PHOLED)

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Phosphorescent organic light-emitting diodes (PHOLED) are a flexible, transparent and highly efficient next-generation technology for realizing new types of display and solid-state lighting applications. However, acceptably long lived blue PHOLEDs and a deep blue-emitting source to generate a standard RGB color space are notably missing. The difficulties arise from the highly energetic nature of blue emission that can overburden and damage the organic molecules comprising PHOLEDs. Also, blue light is dimly perceived by human eyes, requiring higher driving levels and compounding the problem. Here, we demonstrated solutions that directly tackle these issues in the blue PHOLEDs. In our first presented work we minimized the highly destructive process to that degrades the organic materials, which occurs when two useful excited states collide with each other. By minimizing this process, we demonstrated 10 times improvement in the operational lifetime of the sky blue PHOLEDs. This was done by reducing the local density of emissive states in the device emission zone. In our second presented work, we proposed a design approach to make emission-deactivating states inaccessible in deep blue-emitting iridium (III) phosphors, thereby achieving exceptionally high brightness and deep blue color PHOLEDs. Results from our two papers are fundamental yet practical to advancements to current OLED technologies.
Ptychographic Imaging on a High Harmonic Generation X-Ray Source

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Coherent diffraction imaging (CDI), or so-called lens-less imaging, is a novel technique in which the diffraction pattern(s) from a sample is used to reconstruct a high resolution image via iterative phase retrieval techniques. Specific types of CDI have been developed such as ptychography, in which multiple diffraction patterns of the same sample are recorded from overlapping locations on the sample. The overlap of these diffraction patterns makes than phase retrieval more robust than is possible with single diffraction pattern reconstructions. The work detailed in this presentation is focused on the implementation of an automated ptychographic imaging system on both a tabletop HeNe laser setup and a tabletop high harmonic generation (HHG) x-ray source. Reconstructions were then performed using scripts written in Matlab. Applications of this work are numerous, encompassing the imaging of any objects of interest at nanometer resolution.
Graphene Ambipolar Nanoelectronics for High Noise Rejection Amplification

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In modern wireless communication system, signal amplification is critical for overcoming losses during multiple data transformations/processes and long-distance transmission. Common mode and differential mode are two fundamental amplification mechanisms, and they utilize totally different circuit configurations. Here we report a new type of dual-gate graphene ambipolar device with the capability of operating under both common and differential modes to realize signal amplification. The signal goes through two stages of modulation, where the phase of signal can be individually modulated to be either in phase or out of phase at the two stages by exploiting the ambipolarity of graphene. As the results, both common and differential mode amplifications can be achieved within one single device, which is not possible in the conventional circuit configuration. In addition, a common-mode rejection ratio (CMRR) as high as 80dB can be achieved, making it possible for low noise circuit application. These results open up a new direction for graphene based ambipolar electronics that can greatly simplify the RF circuit complexity and the design of multi-function device operation.
Temporal Information Encoding in Dynamic Memristive Devices

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We show that temporal and frequency information can be effectively encoded in memristive devices with inherent short-term dynamics. Ag/Ag2S/Pd based memristive devices with low programming voltage (~ 100 mV) were fabricated and tested. At weak programming conditions, the devices exhibit inherent decay due to spontaneous diffusion of the Ag atoms. When the devices were subjected to pulse train inputs emulating different spiking patterns, the switching probability distribution function diverges from the standard Poisson distribution and evolves according to the input pattern. The experimentally observed switching probability distributions and the associated cumulative probability functions can be well-explained using a model accounting for the short-term decay effects. Such devices offer an intriguing opportunity to directly encode neural signals for neural information storage and analysis.
Silicon Photovoltaics for Infrared Energy Harvesting in mm-Scale Systems

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Human microchip implants are a prospective technology that can be used for a wide range of applications. Low-power microelectronics have enabled these possibilities, though a means for reliable energy harvesting through tissue is required. Harvesting of infrared radiation may provide an attractive alternative compared to RF and Vibration sources, utilizing the infrared transparency window of biological tissue in the 700-900nm range. Silicon photovoltaics provide excellent response in the desired infrared wavelength, an intrinsic compatibility with silicon microelectronics, and do not raise any further concerns over toxicity to humans that could hamper the use of III-V arsenide and phosphide photovoltaics. Highly efficient silicon solar cells are namely optimized for the 700-900nm spectral band and minimization of shunt leakage current that is critical for effective operation under low-flux conditions. In this work, design considerations for silicon infrared photovoltaics will be presented, along with initial experimental results. Device structures based on a thick epitaxial silicon layer on conducting silicon substrate were simulated using Sentaurus-Device to optimize response at 800nm. Anti-reflection coating design, base doping and thickness, emitter doping, and junction width and depth were all co-optimized. Maximum power efficiency of greater than 20% is achieved with a substantial improvement through the introduction of a shallow n-type surface layer. From the initial fabrication processes, fabricated Silicon PV cells that have maximum power conversion efficiency around 10-13% demonstrate improved IR power conversion at 850nm over commercial a-Si and c-Si solar cells. Further improvements may be possible with optimization of shallow junctions and surface passivation processes.
Enhanced light extraction from organic light-emitting devices using a sub-anode grid

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We demonstrate the highly effective extraction of waveguided light from the active region of organic light emitting devices (OLEDs) using a non-diffractive dielectric grid layer placed between the transparent anode and the substrate. The sub-anode grid outcouples all waveguide mode power into the substrate without changing the device electrical properties, resulting in an increase in external quantum efficiency and luminous efficacy for green phosphorescent OLEDs from (15±1)\% and (36±2) lm/W to (18±1)\% and (43±2) lm/W. These characteristics are further increased to (40±2)\% and (95±4) lm/W when all glass modes are also extracted. Using a thick electron transport layer further reduces surface plasmon modes, resulting in an increase in the substrate and air modes by (50±8)\% compared to devices lacking the grids. The sub-anode grid has minimal impact on OLED emission wavelength and viewing angle, and will likely prove beneficial for a broad range of display and lighting applications.
Schottky Diodes Made with Solution-Processed Amorphous Zinc Tin Oxide Semiconductor

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Here we demonstrate vertical Schottky diodes made with solution-processed, amorphous Zn-Sn-O semiconductor. This is the first Schottky diode made with multi-layer solution-processed metal oxides. Evaporated Pt and Pd were used as rectifying contacts at the bottom and sputtered Mo as ohmic contact at the top. The bulk free electron concentration was derived from series resistance model, and depletion charge concentration from impedance spectroscopy. The difference between the two implies deep-level states in amorphous material. Diodes were further analyzed by thermionic emission model, extracting $I_0$, $n$, and $\Phi_b$. Diodes made using oxidized Pd Schottky contacts exhibit a reasonably high rectification ratio compared to Pt due to less Fermi level pinning by oxidation. Thus, the barrier height can be tuned by Schottky contact metal choice and metal treatment. It also exhibits reasonably high forward current density and small ideality factor.
Transforming organic photovoltaics (OPV) into a fully practical energy solution

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Recent improvements in small molecular-weight organic photovoltaics (OPVs) have been realized by controlling the morphology of thin-films down to the nanometer scale. Organic layer morphology affects device efficiencies, operational lifetimes, and failure mechanisms. One method to effectively control the morphology of organic layers is thin film growth of organic vapor phase deposition (OVPD). By using inert carrier gas, OVPD provides extra energy for organic molecules to find an equilibrium morphological configuration, whereas evaporated molecules in conventional vacuum thermal evaporation (VTE) growth proceed ballistically from the source, having little opportunity for reorientation. In this work, we demonstrate OPV cells based on a mixed tetraphenyldibenzoperiflanthen (DBP):C₇₀ heterojunction grown by OVPD with a power conversion efficiency, PCE = 6.7±0.2%, compared to 6.2±0.2% for analogous, optimized devices grown by VTE. The optimized thickness of OVPD cells can be almost four times compared to those grown by VTE. This eases manufacturing tolerances by reducing the occurrence of electrical shorts encountered in thinner cells. In addition, we show that morphological changes over time in the bathophenanthroline (Bphen) cathode buffer layer in these organic solar cells strongly impact device reliability, and that these changes are reduced when the underlying active region of the OPV is grown by OVPD as opposed to VTE. Based on the improvement of OPVs via OVPD technology, we integrated both VTE and OVPD system into one roll-to-roll (R2R) OPV fabrication system. This R2R system enables us to do massive production of OPV in cost-effective manner, demonstrating OPV as a practical energy solution.
High-efficiency AlGaAs indoor photovoltaics

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Low-power photovoltaic energy harvesting allows for the deployment of fully autonomous small-scale sensors in environments not previously possible. Indoor lighting is one of those environments where the illumination intensity is typically below 1,000 lux and the spectrum is narrowly centered in the visible region. Photovoltaics based on III-V compounds provide an outstanding choice for indoor lighting conditions due to their superior absorption, carrier transport, and corresponding high quantum efficiency in the visible spectrum. In this work, studies of GaAs and AlₐGa₁₋ₐAs photovoltaic cells designed for indoor energy harvesting will be reported. The photovoltaic cells are grown by molecular beam epitaxy on GaAs substrates and fabricated using standard photolithography, etching, and deposition techniques. Current-voltage (I-V) measurements under different lighting intensities show the effect of photovoltaic design and fabrication on performance. External quantum efficiency (EQE) measurements demonstrate the correlation between quantum efficiency in the visible wavelengths and light harvesting efficiency (LHE). Fabricated Al₀.₂Ga₀.₈As photovoltaic cells obtain an open circuit voltage of 0.85 V and reach power density levels of up to 291 nW/mm² under white LED illumination at 580 lux. LHEs greater than 0.5 mW/lm have been achieved with fabricated Al₀.₂Ga₀.₈As photovoltaic cells under white LED illumination, much greater than the target LHE for perpetual operation of autonomous small-scale sensors of 0.1 mW/lm. The path for achieving large light harvesting efficiencies will be discussed as well as the implementation of these photovoltaic cells for mm-scale sensing applications.
Fabrication of Tungsten Diselenide Photovoltaic Devices Using Surface-Charge Transfer (SCT) Doping Mechanism

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Two dimensional layered transition metal dichalcogenides (TMDCs, e.g., WSe₂, WS₂, and MoS₂) are expected to be applied on photovoltaic application with its ultra-high light absorption coefficients over a broad range of wavelengths and have been envisioned to enable next-generation ultrathin flexible photovoltaic (PV) devices with excellent performance and low cost. In this work, we exhibit a new up-scalable doping technique which is capable of forming a permanently stable built-in potential in pristine WSe₂ photoactive layers and resulting in high PV performance. This new doping method uses regular deposition processes to coat WSe₂ surfaces with thin-film metals with deterministic work functions (Φ), which can induce sustainable surface-charge transfer (SCT) processes at WSe₂/thin-film material interfaces and result in p-n junctions with deterministic band alignments. We fabricated a WSe₂ photovoltaic device consisting of a vertically stacked high-Φ electrode/few-layer WSe₂/low-Φ electrode/ITO structure. The SCT processes at high-Φ electrode/WSe₂ and WSe₂/low-Φ electrode interfaces can induce p- and n-doping in the WSe₂ photoactive region, respectively, and form a p-n junction at the thermodynamically equilibrium state. Our devices with Zn as top metal show photo-conversion efficiencies (PCE) up to 6.7% under 532 nm illumination and external quantum efficiencies in the range of 40%–83% for visible light. This work provides important scientific insights for improving PV responses of TMDCs. The presented SCT-based doping process can potentially enable the up-scalable manufacturing technologies for TMDC-based ultrathin-film PV cells.
Selector Devices for Crossbar Resistive Memory Arrays

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Crossbar resistive random access memory (RRAM) arrays require selector devices with nonlinear I–V characteristics to address the inherent sneak leakage issues in the one-selector-one-resistor (1S1R) configuration. Numerical simulations have been performed to evaluate the performance requirements of selector devices during the read/write operation of RRAM arrays. The benchmark tradeoff between selector nonlinearity and current density was carefully analyzed to guarantee reliable array operation and provide guidance for developing selector devices. With better understanding on device requirements, we further developed a novel TaO\textsubscript{x} selective layer exhibiting high nonlinearity and excellent uniformity and integrated the selector with HfO\textsubscript{x} based RRAMs. The conduction mechanism of TaO\textsubscript{x} selector has been systematically investigated. These results will provide useful insight into continued scaling and design optimization of crossbar RRAM arrays.
PEN: Power and Energy
Cooperate CdS QDs and Ag@PVP to improve efficiency of Dye Sensitized Solar Cell

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This paper describes cooperate the co-absorbance (CdS QDs) and the plasmonic core-shell nanoparticles (Ag@PVP) of dye synthesized solar cells in which CdS QDs and Ag@PVP are incorporated into the TiO2 layer. Cooperative nanoparticles show superior behavior on enhancing light absorption in comparison with reference cells. Cooperated DSSC exhibits the best performance with the power conversion efficiency of 7.64% which is superior to that of the free–modified DSSC with the PCE of 5%. Detailed studies offer an effective approach to enhance the efficiency of dye synthesized solar cells.
Effect of torrefaction on the pyrolysis of centimeter-scale pine wood particles

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Pyrolysis of centimeter-scale pine wood particles was performed in a vertical tube furnace under 500°C to investigate the effect of torrefaction on the pyrolysis process, product yields and composition of bio-oil. Pine wood was torrefied at different temperatures (225°C, 250°C, 275°C and 300°C) for various times (15min, 25min, 35min). Weight loss and color change of wood samples during torrefaction were examined, which showed hemicellulose decomposed heavily under severe torrefaction. Profiles of solid mass fraction and temperature were recorded for pyrolysis experiment, indicating that torrefaction at 225°C and 250°C had ignorable influence on pyrolysis process while torrefaction at 275°C and 300°C had a significant effect. Influence of torrefaction on the conversion time of large particle pyrolysis was not significant. The yield of three pyrolysis products, liquid, char and gas were calculated and analyzed. GC/MS was used to characterize the organic liquid and we found the acid content in the bio-oil was significant reduced after wood torrefaction at 300°C. The $^{13}$C NMR spectra of the bio-oil were obtained to identify the carbon groups.
Adaptive State Estimation and Control of Thermostatic Loads for Real-Time Energy Balancing

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This work focuses on adaptively controlling thermostatic loads (TLs), such as refrigerators and air conditioners, in order to manage the electrical grid’s real-time energy imbalance. Previous research has used a Markov chain model (MCM) to describe the aggregate temperature dynamics of thousands of TLs. Specifically, this model is used for estimation and prediction of the system’s state within a look-ahead proportional controller. We build upon this work by adaptively controlling the plant in order to reject population-wide disturbances. Such disturbances include ambient temperature swings and coordinated user behavior (e.g. hundreds of refrigerator doors opening around dinner time). We investigate two adaptive control techniques: 1) updating the MCM via online state measurements, and 2) updating the MCM via aggregate-output feedback. Whereas the state-based technique is viable only when significant communication infrastructure is available, the aggregate-output based method can be used with minimal such infrastructure. Both adaptive controllers are compared to benchmark control systems through simulations of a population of 10,000 TLs. The largest improvement in RMS error due to adaptive control occurs when multiple disturbances are affecting the system; in this case the best adaptive method results in an error of 2.78%, as compared with an error of 3.51% with the best benchmark controller. Overall, the simulation results show that the online adaptive control techniques consistently outperform the benchmark controllers.
Magnetoelastic Energy Harvester

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Research presented in this poster focuses on the experimental and theoretical analysis of a compact, nonlinear, broadband energy harvesting device. Cantilevered structure zigzag beams have been shown to have natural frequencies orders of magnitude lower than traditional cantilever beam geometries of the same size. Literature has also demonstrated that a cantilever beam harvester design combined with a magnetic field introduces nonlinearities in the response, which can increase bandwidth of the device. Current energy harvester designs are relatively large in size, are most efficient at high frequencies, or only useful for narrowband linear operation. The proposed research introduces a zigzag geometry beam used in conjunction with a magnetic field to create a compact device capable of low frequency broadband energy harvesting. Experimental and analytical results are shown comparing both the linear and nonlinear energy harvesting capabilities of the zigzag structures.
Shooting Methods for Computation of Parameter Stability Boundaries in Fault Induced Delayed Voltage Recovery

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Electrical power distribution networks are susceptible to Fault Induced Delayed Voltage Recovery. These events are usually initiated by faults at substations, and lead to low voltages throughout the distribution grid that are slow to recover to nominal levels, if they recover at all. The root mechanism behind these phenomena is known to be the stalling of induction motors in residential air conditioners. It is important to determine the stability boundary in parameter space that divides parameters which lead to motor stalling and parameters for which the motors will recover. Novel algorithms are presented for numerically computing the parameter space stability boundary, and for finding the closest distance from an initial set of parameters to the boundary. These are justified by theoretical results which revolve around the presence of a special equilibrium point on the stability boundary, called the controlling unstable equilibrium point, which plays a central role. The key idea of the technique is to vary parameters in order to drive the trajectory to spend a fixed amount of time inside a ball centered at the controlling unstable equilibrium, and then to increase the amount of time inside the ball towards infinity. A proof that this approach is guaranteed to reach the stability boundary is provided under reasonable assumptions. The algorithms are applied to a modified version of the 37-bus IEEE test feeder, and results are discussed.
Temporal Instanton Analysis: Identifying Vulnerability in Transmission Networks

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A wind forecast error that was once inconsequential is now vexatious. As wind grows into a major transmission-scale energy source, system operators find themselves frequently dealing with wind-induced network congestion. Operators use wind forecast data to steer the network, but wind forecasts are significantly less accurate than generation and demand predictions. Might forecast deviations compound across a collection of wind farms to overheat a transmission line? Which lines are most vulnerable to such an event? Temporal instanton analysis addresses these questions by identifying sag-inducing wind patterns and ranking them according to likelihood. Each instanton candidate wind pattern is the solution to a quadratically-constrained quadratic program (QCQP). There are two major contributions from this work: a solution method for the QCQP, and various implementation details that help the method scale to large networks. Ultimately, the intersection of likely wind patterns with those that cause excessive line heating is of interest to system operators and planners, who may use this information to better prepare for renewable generation uncertainty.
Stability Assessment of Vanadium(III) Acetylacetonate Complexes for Non-Aqueous Redox Flow Batteries

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Non-Aqueous Redox Flow Batteries have the potential to make affordable grid-scale energy storage a reality, but low solubility, and poor cycle life have prevented commercialization. Most systems are characterized using charge/discharge of both half-reactions, which prevents the characterization of each half-reaction, separately. In this study, a bulk electrolysis (BE) stability assessment was conducted on both V(acac)₃, and a highly soluble version of V(acac)₃ with ester functional groups, to determine that the primary side product for both species is a vanadyl species which is produced during the cathodic reaction. For V(acac)₃, the cycle life is ~10 cycles, while the side reaction occurs more rapidly for the highly soluble complex, which results in a cycle life of less than one. The stability and charge storage mechanisms for vanadium(III) acetylacetonate were further investigated using BE and X-ray absorption spectroscopy, and then compared to DFT structure optimization calculations using Gaussian 09. The XANES spectra was used to quantify that no statistically meaningful charge is stored on the vanadium atom for the positive and negative reactions of V(acac)₃, which is in agreement with DFT results. DFT and additional BE experiments provide evidence of increased V-O bond length changes for the negative reaction of V(acac)₃ resulting in ligand shedding, and the formation of VO(acac)₂ during the positive reaction which then reacts with the acetonitrile solvent at low potentials. Cyclic Voltammograms of the resulting complex reveal similar electrochemical behavior to V(acac)₃ which illustrates the importance of detailed characterization techniques.
Demand response (DR) refers to changing electric load consumption patterns that help the grid operate more reliably and efficiently. With high penetration of wind and solar in the system, renewable generation can lead to large uncertainty due to its volatility to ambient conditions. To ensure the reliability of the grid, more ancillary services are required to continuously balance the supply and demand. From previous work, researchers have proposed that aggregation of controllable loads can provide ancillary services to the system. Compared with conventional services, DR resources have faster responses, lower costs, and less environmental impacts. However, the capacity of DR resources is uncertain and highly effected by ambient conditions and human behaviors. To handle different types of uncertainties from renewable generation and DR, stochastic optimal power flow was used by introducing chance constraints with probability requirement and an objective to minimize the total operational costs in the system. To qualitatively capture the DR energy state and capacity uncertainty in this optimization problem, a simplified thermal battery model was used to ensure a non-disruptive control to the loads. The problem was solved by both scenario-based methodology and Gaussian-based analytical reformulation on an IEEE 30-bus network for both congested and uncongested cases. We evaluated the results by comparing the objective performance, computational effort and reliability for different methodologies. For analytical reformulation, we also tested the cutting plane algorithm which leads to fast convergence compared with the conventional algorithm.
An Improved Initialization for the AC-QP OPF Method Using an SOCP Relaxation

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Solution methods for the optimal power flow (OPF) problem are well established for traditional electricity networks. However, with increasing demand, there is a growing need for the integration of renewable energy sources. While storage devices are important for the economic operation of renewable generation, their physical properties introduce temporal coupling in the OPF constraints. This requires modifying a traditional OPF problem to a multiperiod OPF formulation. This paper explores combining a traditional multiperiod AC-QP OPF solution method with the SOCP relaxation of the OPF problem. It presents a new use for the SOCP relaxation, as an initialization for the AC-QP OPF algorithm. This new combined method is demonstrated on several test cases, including modified IEEE test networks and the Western Electricity Coordinating Council (WECC) network. Benefits with respect to the convergence rate, execution time, and quality of solution of this updated method are demonstrated by comparing the performance of the AC-QP OPF method when initialized using two other methods.
Corrective Model-Predictive Control in Large Electric Power Systems

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Current trends in electric power systems indicate that distributed energy resources such as renewables, storage, and controllable loads will become more prevalent in the coming years. These devices offer options for increased control of power flows throughout electricity networks but often are not utilized to their full potential. During emergency situations, system operators may ignore the capabilities of these devices since straightforward protocols for their use over a broad range of operating scenarios have not been defined and the number of control actions required to operate them may be overwhelming. Model-Predictive Control (MPC) has demonstrated its ability to effectively utilize these devices to provide reliable control during emergency situations on models of small power systems. However, realistic power systems often have thousands of buses and are significantly larger than these test networks. Additionally, the current state-of-the-art algorithms in this area are based on the DC power flow, which ignores voltage magnitudes and reactive power. This work presents an implementation of MPC based on the more accurate AC power flow model, which incorporates voltage magnitudes and reactive power. The increased accuracy of this model comes with increased computational costs, which test the limits of commercially available optimization solvers. To address this issue, network reduction techniques are applied to reduce the problem size. By selecting a subset of controls and utilizing the Kron reduction method, the proposed approach increases the controller accuracy while reducing the solution time. Results are demonstrated on a 4200-bus model of the actual California electric grid.
Power Systems Scheduling Incorporating Histogram Control of Electric Loads with Energy Storage

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This research addresses the challenge of scheduling and controlling a large population of electric loads by incorporating a physically-based aggregate model of the population into power systems scheduling applications, such as the day-ahead unit commitment (UC). Alongside standard generation control, electric loads can contribute to lower costs, reduce emissions and meet security criteria. In particular, the energy storage capability of large populations of electric loads such as electric water heaters, space heaters, air-conditioners, and electric vehicles offer significant flexibility to manipulate their aggregate demand without inconveniencing their users. Controlling the demand of a large population of distributed loads is however complicated due to the randomness in usage, the difficulties in managing the post-control payback effects and the computational complexities associated with integrating physical load models into the MILP structure of UC. These issues have been addressed via several innovations: (i) modeling the dynamics of the load population via histograms transition equations; (ii) consideration of a large controllable temperature range over which heater distributions of many different shapes may exist; (iii) finding the specific stationary shapes that have minimum overlaps with the uncontrollable temperature zones; (iv) from such histograms, computing the bounds on the number of heaters that can be turned on/off in terms of the energy stored; (v) incorporating these bounds into the UC to find optimal charging schedules; (vi) developing an intra-hour scheme whereby individual loads self-dispatch to meet the UC schedules. Numerical simulations illustrate the applicability and benefits of our proposed approach.
Spatial Multi-objective Optimization of Electricity System in Indonesia: The Role of Renewable Energy in a Sustainable Energy System

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Indonesia is blessed with significant fossil and renewable energy resources. However, high disparity on population density, infrastructure, economic level, and the dislocation between energy source and energy load location among and inter-region inflict to discrepancy on electricity system performance among regions. This research develop a multi-objective optimization model for Indonesian power generation planning up to 2050. In order to capture more accurately regional characteristics, the model was developed in spatial as well as national approach by dividing Indonesia become six regions: Sumatera, Java-Madura-Bali (Jamali), Kalimantan, Sulawesi, Maluku-Nusa Tenggara (Maluku & NT), and Papua. Five scenarios were proposed: (A) business as usual, (B) passively environment oriented, (C) economic-environmental balance, (D) actively environment protection, and (E) totally towards green society. The results from optimization model were inputted in sustainability indicator simulation which consist of eleven indicators which are represent three sustainability aspect: economic, social, and environment to be analyzed. The results show that national approach could utilize more renewable energy than spatial approach due to no limitation on potential coverage area. Passively environment oriented provide the best sustainable indicator performance. The scenario slightly compromise cost of electricity generation to highly increase social and environment aspects by increasing penetration of renewable energy.
A Methodology for Generation Expansion Planning in Restructured Electricity Industry

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In the restructured electricity industry, generation expansion planning (GEP) is an oligopoly of strategic Generation Companies (GenCos) with private information investing in a highly uncertain environment. Strategic planning and uncertainties can result in market manipulation and underinvestment. We consider investment and generation decisions simultaneously in a general framework of $N$ firms and $T$ years planning horizon and propose a forward moving approach for GEP that allows GenCos to adjust their plans based on the changes in the environment. We also propose an expansion block mechanism that the system operator can apply and has the following features. (F1) It is individually rational. (F2) It is budget balanced. (F3) The expansion and production allocations corresponding to the unique Nash Equilibrium (NE) of the game induced by the mechanism is the same as those that maximize the sum of utilities of the producers and the demand. (F4) It is price efficient that is, the price for electricity at equilibrium is marginal utility of the demand and marginal cost of production by producers with free capacity.
Characterizing the stability of Li$_7$La$_3$Zr$_2$O$_{12}$ solid state electrolyte and lithium anode interface as a function of current density

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Li-ion battery technology has advanced significantly in the last two decades. However, future energy storage demands will require safer, cheaper and higher performance electrochemical energy storage. While the primary strategy for improving performance has focused on liquid electrolyte Li-ion battery chemistries, this work supports the development of solid-state batteries employing Li metal anodes. One approach to stabilize Li anodes entails the replacement of a liquid with a solid electrolyte. Recently, the ceramic electrolyte, Li$_7$La$_3$Zr$_2$O$_{12}$ (LLZO) cubic garnet, has shown promise owing to its unique combination of properties such as high Li-ion conductivity (1 mS/cm at room temperature) and electrochemical stability between 0-6 V vs. Li/Li$^+$. While understanding and characterizing these properties has been intensely studied, little is known about the maximum sustainable current density in LLZO. The purpose of this work is to present one of the first studies to evaluate the stability of the Li-LLZO interface as a function of current density. Specific attention is given to LLZO phase purity, density, and surface preparation. The LLZO was densified using a rapid densification process achieving > 97% relative density, with < 10% grain boundary resistance; effectively consisting of an ensemble of single LLZO crystals. DC cycling, comprehensive electrochemical impedance spectroscopy, x-ray photoelectron spectroscopy, and atomic force microscopy were used in a concerted effort to determine the reactions that govern the maximum sustainable current density of the Li-LLZO interface.
Sequential Contracts for Uncertain Renewable Energy Resources

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We propose a two-time step model to capture the dynamically varying nature of renewable generation and to provide a general formulation for sequential contract design for renewable resources. Based on this model, we formulate and solve two flexible contract design problems, assuming private and public observation of the ex-post information available at time two (e.g. wind speed realization), respectively. We compare the flexible contracts with the corresponding firm contract. We show that all three forward contracts can be interpreted as menus of payment vs. quantity curves offered by the buyer to the seller. We prove that sequential flexible contracts are more beneficial for the buyer than firm contracts. We also show that the monitoring of ex-post information benefits the buyer. However, the effect of such monitoring on social welfare depends on the environment.
Nanoporous Aramid Nanofiber Separators for Non-Aqueous Redox Flow Batteries

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Redox flow batteries (RFBs) possess a unique combination of attractive attributes including decoupled power and energy storage capacities, low cost, and high efficiencies, and are promising for large-scale energy storage. A significant challenge in the development of high energy density, non-aqueous systems is the lack of selective membrane/seperator materials. This poster describes a novel nanoporous separator based on aramid nanofibers (ANF) produced using a spin-coating, layer-by-layer technique. The multilayer structure yields 5 nm pores, enabling nanofiltration and high selectivities, in terms of the transport of species with differing sizes. Vanadium acetylacetonate (V(acac)₃), a candidate for non-aqueous RFB electrolytes, was used as the model active species. Its permeability through the ANF separator was an order of magnitude lower than that for Celgard 2325, a commercial separator while the support conductivities were comparable. The combined effect resulted in a doubling of the coulombic and energy efficiencies for cells using V(acac)₃ based electrolytes. For asymmetric cells with solutions of V(acac)₃ as the negative electrolyte and ferrocene as the positive electrolyte, a 60% improvement in coulombic efficiency was achieved using the ANF separator over Celgard. The results demonstrate the feasibility of using ANF separators for symmetric and asymmetric non-aqueous RFBs and encourages further development.
Exploring the Rechargeability of a Non-Aqueous Mg/O₂ Battery

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By combining a multivalent cation with the high capacity of a gas-breathing positive electrode, the energy density of a non-aqueous Mg/O₂ battery is projected to surpass that of other ‘beyond-Li-ion’ chemistries. Nevertheless, research into Mg/O₂ systems has been limited. A rechargeable, non-aqueous Mg/O₂ cell that operates at room temperature will be discussed and used to clarify fundamental electrochemical characteristics, including the nature of the product phase(s) and the reaction mechanism for discharge. The discharge product differs from alkali-metal-based chemistries in that it is a mixed phase, primarily comprising crystalline MgO, with a substantial minority of MgO₂. The open-circuit cell voltage is 2.0 V, lower than the theoretically expected ~2.9 V. Both the low voltage and the two-phase discharge product are consistent with a multi-step discharge reaction in which a superoxide (O₂⁻) intermediate forms at ~2 V vs. Mg/Mg²⁺. Chemical reactions subsequently yield MgO₂ and MgO, but do not contribute to the cell’s electrical energy output. During charging, MgO₂ is preferentially decomposed. Bypassing the multi-step discharge mechanism in favor of direct electrochemical formation of MgOₓ would allow for a higher discharge potential and, consequently, higher energy density.
SEC: Software Engineering and Computer Science
We show that the next generation of exascale systems with hundreds of petabytes of memory can be constructed with emerging 3D DRAM and flash memory for checkpointing. In other words, more speculative, expensive, futuristic memory technologies will be unnecessary, at least for the next generation. Such systems pose two challenges. 1) integrated 3D die-stacked memory will increase capacity and bandwidth, but would also experience more errors; and 2) flash memory is slow to program and has low endurance. At exascale, these shortcomings are exacerbated because of the hundreds of thousands of memory chips. We show that these two challenges can be overcome by combining two fault tolerance techniques: error correcting codes and checkpointing. Specifically, we propose a two-tier error correcting mechanism, that uses a Reed-Solomon code, and that improves the error probability of an exascale node by $547 \times$ over existing rotational codes. It limits the error probability to $10^{-7}$ and the checkpointing overhead of an exascale node is reduced from 27% to 2.5% of application runtime while reducing checkpointing energy by $2.9 \times$. Additionally, we use 3D MLC and TLC NAND flash for checkpointing and show that our combined ECC and checkpointing approach can prolong the lifetime of flash devices for up to 6 years and 2 years, respectively.
Learning useful abstractions from unstructured data

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When the amount of training data is limited, the successful application of machine learning techniques typically hinges on the ability to identify useful features or abstractions. Expert knowledge often plays a crucial role in this feature engineering process. However, manual creation of such abstractions can be labor intensive and expensive. In this paper, we propose a feature learning framework that takes advantage of the vast amount of expert knowledge available in unstructured form on the Web. We explore the use of unsupervised learning techniques and non-Euclidean distance measures to automatically incorporate such expert knowledge when building feature representations. We demonstrate the utility of our proposed approach on the task of learning useful abstractions from a list of over two thousand patient medications. Applied to three clinically relevant patient risk stratification tasks, the classifiers built using the learned abstractions outperform several baselines including one based on a manually curated feature space.
Data Selection for Acoustic Emotion Recognition: Analyzing and Comparing Utterance and Sub-Utterance Selection Strategies

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Data selection is an important component of cross-corpus training and semi-supervised/active learning. However, its effect on acoustic emotion recognition is still not well understood. In this work, we perform an in-depth exploration of various data selection strategies for emotion classification from speech using classifier agreement as the selection metric. Our methods span both the traditional utterance as well as the less explored sub-utterance level. A median unweighted average recall of 70.68\%, comparable to the winner of the 2009 INTERSPEECH Emotion Challenge, was achieved on the FAU Aibo 2-class problem using less than 50\% of the training data. Our results indicate that sub-utterance selection leads to slightly faster convergence and significantly more stable learning. In addition, diversifying instances in terms of classifier agreement produces a faster learning rate, whereas selecting those near the median results in higher stability. We show that the selected data instances can be explained intuitively based on their acoustic properties and position within an utterance. Our work helps provide a deeper understanding of the strengths, weaknesses, and trade-offs of different data selection strategies for speech emotion recognition.
SPS: Space and Planetary Sciences
Differential flow: Locally Generated or Coronal Artifact?

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Alpha particles and proton beams differentially flow in the solar wind with respect to the proton core by about an Alfvén speed. Whether differential flow is an artifact of coronal physics or a signature of local acceleration as the solar wind propagates earthward is undetermined. A new analysis of Wind spacecraft observations in the solar wind combines Faraday Cup ion distribution functions with vector magnetic field measurements to characterize the bulk properties of the proton core, proton beam, and alpha particles with 92s time resolution. We utilize this data set to examine the occurrence of differential flow at 1 AU as a function of solar wind conditions and other parameters. We discuss the implications of observed trends on our understanding of differential flow’s origin.
Thermospheric Wind Effects on the Evolution of Dayside Ionospheric Total Electron Content (TEC)

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The ionospheric electron density is a highly varying quantity and significantly affects the propagation of radio signals that pass through or are reflected by the ionosphere. During moments of enhanced geomagnetic activity, in particular geomagnetic storms, ionospheric total electron content (TEC) anomalies can form with very severe spatial and temporal gradients. Occasionally, these anomalies can be large enough to reduce the accuracy of positioning and timing service from GPS causing serious problems for planes and other systems. This research targets a particular TEC structure, TEC plumes, a region of high TEC extending from mid-latitudes to higher latitudes and polar areas in the north hemisphere. It has been found recently that the growth and decay of the plumes can be affected by interplanetary conditions through convection as well as thermospheric winds. In particular, this research focuses on the thermospheric wind effects on plume evolution in terms of longitudinal and hemispheric asymmetries. We use the International Geomagnetic Reference Field (IGRF) model to specify the geomagnetic field lines as well as idealized thermospheric wind patterns to identify the wind effects at different longitudes. We found that thermospheric wind would be most effective in changing TEC at two longitudinal sectors in the Northern Hemisphere, i.e. near Alaska and East Europe, and one longitudinal sector in the Southern Hemisphere, i.e. near Antarctic Peninsula. We also compare the results to TEC data through event and statistical analysis and to ionosphere-thermosphere simulation results. Preliminary results show that the TEC value dips are coincident with these longitudinal sectors.
Continuous solar wind forcing knowledge: Providing continuous conditions at Mars with the WSA-ENLIL+Cone model

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Knowledge of solar wind conditions at Mars is often necessary to study the planet’s magnetospheric and ionospheric dynamics. With no continuous upstream solar wind monitor at Mars, studies have used a variety of methods to measure or predict Martian solar wind conditions. In situ measurements, when available, are preferred, but can often be limited in continuity or scope, and so studies have also utilized solar wind proxies, spacecraft flybys, and Earth-Mars alignment to provide solar wind context. Despite the importance of solar wind knowledge and the range of methods used to provide it, the use of solar wind models remains relatively unutilized. This study uses the WSA-ENLIL+Cone solar wind model to calculate solar wind parameters at Mars' orbital location to provide a new approach to determining solar wind conditions at Mars. Comparisons of the model results with observations by the MAVEN spacecraft indicate that the WSA-ENLIL+Cone model forecasts solar wind conditions at Mars as accurately as at Earth, although at Mars the model systematically mispredicts solar wind speed and density, likely a result of magnetogram calibration. These results suggest that solar wind models can be used to provide the necessary context to planetary studies.
Statistical comparison of inter-substorm timings in global magnetohydrodynamics (MHD) and observations

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Magnetospheric substorms are events in which energy stored in the magnetotail is released into the auroral zone. Because of the complex, and possibly chaotic nature of substorm energy release, it may be difficult to forecast individual substorms in the near term. However, the inter-substorm timing (the time elapsed between substorms) can be reproduced in a statistical sense, as was demonstrated by Freeman and Morley using the Minimal Substorm Model (MSM), a simple solar-wind driven model with the only free parameter being a recurrence time. The goal of the present work is to reproduce the observed distribution of inter-substorm timings with a global MHD model. The period of 1-31 January 2005 was simulated using the Space Weather Modeling Framework (SWMF), driven by solar wind observations. Substorms were identified in the model output by synthesizing surface magnetometer data and by looking for tailward-moving plasmoids. Substorms identified in the MHD model are then compared with several sources of observational data. For each dataset (MHD model and observations), we calculate the substorm occurrence rate, and for the MHD model we additionally calculate the timing error of the substorm onsets relative to the observed substorms. Finally, we calculate distribution functions for the inter-substorm timings in both the observations and the model. The results of this analysis will guide improvements to the MHD-based substorm model, including the use of Hall MHD and embedded particle in cell (EPIC), leading to a better reproduction of the observed inter-substorm timings and an improved understanding of the underlying processes.
GPU Beamforming and Pulsar Science with the Long Wavelength Array

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The Long Wavelength Array station in Owen’s Valley views a very low part of the electromagnetic spectrum, looking at the band between 28-88 MHz. It also has an abnormally large field of view of 130 degrees, allowing it to see nearly the whole sky. Through a process called beamforming, we take a weighted sum of the inputs from each of the 256 antennas to focus on a particular point in the sky, forming a “beam”. This process is implemented with GPUs to give us the ability to beamform and track sources in real time. We then use this array to observe pulsars in the sky, measuring various characteristics such as Dispersion Measure and how they change when they are close to the sun.
The Dynamics of Coronal-Hole Boundaries


The source of the slow solar wind at the Sun is the subject of intense debate in solar and heliospheric physics. Because the majority of the solar wind observed at Earth is slow wind, understanding its origin is essential for understanding and predicting Earth’s space weather environment. In-situ and remote observations show that, compared to the fast wind, the slow solar wind corresponds to higher freeze-in temperatures, as indicated by charge-state ratios, and more corona-like elemental abundances. These results indicate that the most likely source for the slow wind is the hot plasma in the closed-field corona; however, the release mechanism for the wind from the closed-field regions is far from understood. Here we present the first fully dynamic, 3D MHD simulations of a coronal-hole boundary driven by photospheric convective flows. We determine in detail the opening and closing of coronal flux due to photospheric motions at the base of a helmet streamer. These changes should lead to the release of plasma from the closed magnetic field at the edge of the streamer. Our analysis demonstrates that the bulk of the release is due to interchange reconnection. We discuss the implications of our results for theories of slow-wind origin, in particular the S-Web model, and the implications of our results for observations, such as those from the upcoming Solar Orbiter and Solar Probe Plus missions.
A recent analysis of solar wind charge state composition measurements from the ACE/SWICS instrument showed that the expected correlation between the frozen-in values of the O7/06 and C6/C5 ratios was violated in ~5% of the slow solar wind in the 1998-2011 period (Zhao et al. 2015). In this work we determine that such anomalous behavior is also found in over 40% of Interplanetary Coronal Mass Ejections (ICMEs), as identified by Richardson and Cane (2010). An analysis of the plasma composition during these events reveals significant depletions in densities of fully stripped ions of Carbon, Oxygen, and Nitrogen. We argue that these events are indicators of ICME plasma acceleration via magnetic reconnection near the freeze-in region of Carbon and Oxygen above the solar corona.
TCB: Tissue Cellular and Biomedical Engineering
Tensile Forces Induce Differentiation of Human Embryonic Stem Cells

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Cells interact with their environment through cell-cell and cell matrix adhesion in the body. The function of chemical cues, adhesion signals, and transcription factors have been studied intensively to understand how cells in the embryo differentiate into specific lineage, but these morphogens are insufficient to explain how tissues are assembled during the early development. However, not to much attention has been put studying mechanical stresses to which cells are exposed or in understanding the role of forces (i.e. tensile, compression) in guiding human embryonic stem cell (hESC) differentiation. In this work, we investigate the role of tensile forces in hESCs by utilizing mechanical stress. We explored whether hESCs will respond to external stress. We seeded approximately 10,000 undifferentiated single hESCs into channels and approximately 50-100 cells localized in the area of the channel to be stretched. After applying uniaxial tensile force, substances used as transcription factors such as Sox2 remained in the nucleus, while Nanog and Oct3/4 shuttle from nucleus to cytoplasm, which may indicate that these transcription factors are mechano-sensitive. Nucleo-cytoplasmic Nanog and Oct4 may direct cell programing and determine the cell lineage in early embryo development. These findings might help us to better understand the effect of mechanical forces during development and help us correct defects and to treat diseases.
Tunable control over tolerogenic responses using polymer-antigen conjugate immune-modifying nanoparticles

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There are over 80 types of autoimmune diseases, which affect over 50 million Americans. Current treatment strategies involve systemic administration of non-specific immunosuppressive agents with side effects including susceptibility to opportunistic infections, viral reactivation, and neoplasia. The goal of treating T cell-mediated autoimmunity is to selectively inhibit autoreactive T cells. Intravenous delivery of antigen (Ag) coupled to host splenocytes (Ag-SP) has shown promise in a phase 1 clinical trial, but the cost and complexity to widely implement this strategy will limit its clinical translation. To overcome this, biodegradable poly(lactide-co-glycolide) (PLG) nanoparticles (NPs) were used as vehicles to deliver Ag via surface coupling and encapsulation methods. Though effective in multiple animal models of Th1/17-mediated autoimmune diseases, Ag coupling can deteriorate physicochemical properties (e.g. size, zeta potential, and stability) of the NPs, and Ag encapsulation can result in undesirable and premature Ag release kinetics. The following work describes the production of Ag-polymer conjugates as precursors for formulating Ag-loaded NPs. These polymer-conjugate NPs (pcNPs) display favorable physicochemical properties and are capable of achieving precise Ag loading of single or multiple Ags as well as traceable fluorophores. In vitro, we studied the effect of tunable Ag delivery on the induction of anti-inflammatory regulatory T cells. In vivo, pcNPs demonstrated efficacy in treating the mouse model of MS, experimental autoimmune encephalomyelitis (EAE). PcNPs represent an enabling technology that provides the precision and tunability required for the translation of NP treatments for autoimmune diseases.
Synthetic Poly(ethylene glycol) Hydrogel as a Matrix for Artificial Ovary

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Autotransplantation of cryopreserved ovarian tissue is an emerging solution for premature ovarian failure induced by cytotoxic chemotherapy treatments for cancer and autoimmune diseases. However, there is the risk of re-introducing malignant cells and tissue ischemia cause premature graft failures due poor revascularization. To address these limitations, we engineered an artificial ovary from immature follicles using synthetic hydrogel, poly(ethylene glycol) vinyl-sulfone (PEG-VS), as a supportive matrix. Enzymatically isolated follicles from 7 days old mice were encapsulated in 7% PEG-VS hydrogels modified with 0.5mM RGD and crosslinked with tri-functional MMP sensitive peptide. And then, PEG hydrogels with the encapsulated follicles were orthotopically implanted into ovariectomized mice to investigate the ability of PEG hydrogel to support folliculogenesis and steroidogenesis in vivo. Histological evaluation of the explanted grafts 30 days after implantation revealed multiple fully-developed antral follicles and corpus lutea, which corresponded with normal physiological levels of circulating follicle stimulating hormone (FSH). The FSH levels declined to physiological levels 49 days after transplantation indicating successful restoration of the Hypothalamus-Pituitary-Gonadal axis. The proportion of growing follicles continuously increased over 60 days. However, the total number of follicles in grafts decreased, which correlates with immature follicles entering the growing pool every estrous cycle. Analysis of the grafts 60 days after implantation also revealed functioning blood vessels with red blood cells present inside, demonstrating the capability of PEG hydrogels to undergo remodeling. In summary, our results demonstrate that synthetic PEG hydrogels successfully supported folliculogenesis, steroidogenesis and neovascularization of an artificial ovary for 60 days in vivo.
Rheology and Microstructure of Infectious Fibrin Clots

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Bloodstream infection is a major cause of death and disability in the United States and is frequently medical device related. We have observed infectious clots with bacteria entangled in the fibrin network on intravascular catheters. Fibrin is primarily responsible for the mechanical properties and microstructure of a thrombus. Here, we seek to understand how biofilm-producing bacteria influence fibrin networks. We hypothesize that the presence of S. epidermidis alters both the bulk mechanical properties and the microstructure of fibrin networks. Storage and loss moduli were determined for rabbit, platelet-free plasma (PFP) with (infected clot) and without (pure clot) the presence of S. epidermidis (10⁹ cells/ml) using an AR-G2 rheometer. The microstructures of these simulated thrombi were evaluated by fluorescent labeling of the fibrin and bacteria and visualization with confocal laser microscopy. During PFP clotting, both G’ and G” increased about two decades, indicating a transition from a liquid-like fluid to a solid-like fibrin gel with a G’ more than 10 times larger than G’. When S. epidermidis was added to PFP, however, the clotting process was slowed and G’ and G” increased only one decade. Confocal microscopy demonstrates thrombus-rich biofilm formation. The bacteria in this networks demonstrate at least two distinct populations, those that remain adhered to fibrin and form biofilms, and those that are free and are transported by convection of blood. Here we demonstrate significant variation in the bulk rheology and microstructure of fibrin clot formed in the presence of S. epidermidis compared to sterile clots.
The development and animal testing of thin-wall, high microchannel volume scaffolds for central and peripheral nerve repair

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Approximately 1.9% of the US population experiences permanent nerve damage. One approach to nerve repair is to engineer microchannel scaffolds that provide physical cues to linearly guide regenerating neurons. However, of the microchannel scaffolds under development, the scaffold walls typically occupy more than 50 vol% of the scaffold, which inhibits complete nerve repair. Therefore, the purpose of this work is to develop scaffolds with significantly higher open volume by reducing the thickness of the walls of the scaffolds. Poly caprolactone (PCL) was selected as the scaffold materials owing to its strength to withstand the stresses during fabrication, implantation, and nerve regeneration. Also it is FDA approved. However, PCL has an order of magnitude higher elastic modulus compared to nerve tissue, which may compromise biocompatibility. To reduce the elastic modulus, porosity was introduced using a salt-templating process (6 µm avg pore size). The elastic modulus of non-porous PCL was reduced from 182.1 to 2.1 MPa for 70 vol% porous PCL. The salt-leeching process was translated into scaffolds with an open microchannel volume of over 85% using a novel scaffold fabrication technology. The microchannels consisted of thin-wall (30-60 µm thick) salt-leeched PCL tubes. To test for in vivo efficacy, scaffolds were implanted in the central and peripheral nervous system. This work demonstrates that thin-wall, high microchannel volume scaffolds is a promising approach in restoring nerve damage.
Localized lentivirus delivery via peptide interactions

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Gene delivery from biomaterial scaffolds has been employed to induce the expression of tissue inductive factors for applications in regenerative medicine. The delivery of viral vectors has been described as reflecting a balance between vector retention and release. Herein, we investigated the design of hydrogels in order to retain the vector at the material in order to enhance transgene expression. Poly(ethylene-glycol) (PEG) hydrogels were modified with poly-L-lysine (PLL) to non-covalently bind lentivirus. For cells cultured on the hydrogels, increasing the PLL molecular weight from 1 kDa to 70 kDa led to increased transgene expression. The incubation time of the virus with the hydrogel and the PLL concentration modulated the extent of virus adsorption, and adsorbed virus had a 20% increase in the half-life at 37 °C. Alternatives to high molecular weight PLL were identified through phage display technology, with peptide sequences specific for the VSV-G ectodomain, an envelope protein pseudotyped on the virus. These affinity peptides could easily be incorporated into the hydrogel, and expression was increased 20-fold relative to control peptide, and comparable to levels observed with the high molecular weight PLL. The modification of hydrogels with affinity proteins or peptides to bind lentivirus can be a powerful strategy to enhance and localized transgene expression.
Differential impact of plasma proteins on the adhesion efficiency of vascular-targeted carriers (VTCs) in blood of common laboratory animals

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Vascular-targeted carrier (VTC) interaction with human plasma is known to reduce targeted adhesion efficiency in vitro. However, the role of plasma proteins on the adhesion efficiency of VTCs in laboratory animals remains unknown. Here, in vitro blood flow assays are used to explore the effects of plasma from mouse, rabbit and pig on VTC adhesion. Porcine blood exhibited a strong negative plasma effect on VTC adhesion while no significant plasma effect was found with rabbit and mouse blood. Ultra-high density poly(ethylene)-glycol (PEG) on VTCs was effective at improving adhesion of micro-sized, but not nano-sized, VTCs in porcine blood. Overall, the results suggest that porcine models, as opposed to murine, can serve as a better model in preclinical research for predicting the in vivo functionality of VTCs for use in humans. These considerations hold great importance for the design of various pharmaceutical products and development of reliable drug delivery systems.
Reduction of Bmi-1 Expression by siRNA Loaded “Smart” Nanoparticles in Cisplatin Resistant Head and Neck Squamous Cell Carcinoma

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Numerous studies exhibited that a subpopulation of cancer cells named Cancer Stem Cells (CSCs) is the main reason for tumor imitation, progression, metastasis and increasing of chemoresistance and radioresistance. In Head and Neck squamous cell carcinoma (HNSCC), CSCs have an important role in tumor relapse. Polycomb group protein (PcG) is a chromatin modifier that implicated in the maintenance of the embryonic and adult stem cells and involved in tumor recurrence progression and resistance. Bmi-1 is a member of PcG that shows high expression and represents one of the CSCs markers with many other markers. The main thought that targeting Bmi-1 by knocking down its expression will be a good way to eliminate CSCs. Bmi-1 Knockdown through silencing RNA (siRNA) molecules is a promising approach to reduce the stemness characters of HNSCC. Lack of an efficient biocompatible carrier that can achieve targeting of the diseased cells and not effecting neighboring healthy ones represent one of the most challenges in siRNA delivery. A degradable, pH-sensitive, β-Cyclodextrin based polymeric carrier that condenses siRNA forming “smart” nanoparticles was fully synthesized in our laboratory. Nanoparticles were successfully internalized, escaped from the endosome to deliver the RNA molecules into the cytoplasm of UM-SCC-22B Cis 1R and UM-SCC-22B Cis 12R cell lines. Results exhibited those anti-Bmi-1 nanoparticles which were condensed at N/P ratio of 2.5/1 suppressed Bmi-1 protein levels by 90% and 75.4% in Cis 1R and Cis 12R cells, respectively. Cell viability assay exhibited decrease in IC50 and IC75 for Cisplatin in Cis 12R from 3.1 µM to 1.9 µM and from 6.2 µM to 4.7 µM and in Cis 1R from 2.5 µM to 1.4 µM and from 7.1 µM to 2.9 µM, respectively. Results show promising evidence that our thoughts may be right with high degree.