Bioengineering
SUMMARY: In the last few years, we have shown that neuromodulation using epidural stimulation of the lumbosacral spinal cord can activate latent neural circuits and restore autonomic functions, voluntary movement, standing and stepping in individuals with chronic spinal cord injury. Our current work is focused on advancing the neuromodulation technology while studying the mechanisms of plasticity associated with restoration of function. The implementation of closed-loop controls of stimulation parameters and sequences will allow the translation of stimulation paradigms to the home and community. The integration of multi-system stimulation is expected to have a greater quality of life impact for individuals with SCI.
SUMMARY: Although accidental falls are a common cause of injury in children, a history of a fall is the most commonly stated false scenario provided by caregivers to conceal physical abuse. Whether or not short distance falls can lead to fatal or severe head injury in children is an on-going controversy debated in courtrooms and the scientific literature. In this study we described fall characteristics, resulting injuries and head biomechanics associated with falls involving young children in a childcare setting using video monitoring and wearable biometric devices. We video recorded 3255 falls – in 17% of falls head acceleration and velocity were recorded. Only 6 falls led to minor injuries. The maximum linear head acceleration (50.2 g) and maximum angular head acceleration (5388 rad/s²) occurred when a child tripped and fell forward impacting his head on the edge of a wooden bookcase. To our knowledge this was the first study to analyze a large number of video-recorded falls involving young children, including a subset of falls with directly measured head biomechanics. These biomechanical measurements also provided a direct link between injury outcomes and head accelerations.

Award No. 2017-DN-BX-0158, from the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice

Video monitoring of young children in a childcare setting. Children were equipped with wearable devices that included tri-axial accelerometers and gyroscopes enabling real-time measurements of head acceleration and velocity. This fall involving direct head impact onto the edge of a bookshelf led to the highest levels of head acceleration.

This research was conducted by the University of Louisville Injury Risk Assessment and Prevention Laboratory. This study was conducted at the Bluegrass Academy Childcare Center.
SUMMARY: Child abuse is a public health epidemic with devastating consequences for young children. In 2017, there were 676,000 victims of child abuse and neglect in the U.S. including 1700 deaths. Young children are especially vulnerable - 81% of these deaths occurred among children 0-3 years old. Physical child abuse results in over 120,000 cases a year but accounts for over half of the fatalities. Fractures are the most common serious injury from physical abuse, occurring more often than abuse-related traumatic brain injury and abdominal injury combined. Each year in the U.S. there are more than 90,000 emergency department visits for fractures in children age 0-5 years, with abuse-related fractures peaking in the first 3 years of life. It is extremely difficult for physicians to differentiate abuse-related fractures from those associated with an accident in these young children. To address this need, we developed and tested a fracture injury plausibility assessment model in children with long bone fractures. We demonstrated the model’s capability to differentiate abuse-related fractures from those resulting from accidental trauma, and also demonstrated its potential to decrease race/ethnic disparities in rates of abuse evaluations. The goal of this study is to further validate our evidence-based model for fracture assessments to improve the clinician’s ability to differentiate abuse from accidental fractures in young children.

Award No. R01HD102428 from the National Institutes of Health, National Institute of Child Health and Human Development

Drs. Gina Bertocci, Karen Bertocci, Nathan Brown Bioengineering
Dr. Mary Clyde Pierce, Lurie Children’s Hospital
Dr. Angela Thompson, Engineering Fundamentals

Comparison of accidental vs. abusive fractures in children 0-48 months of age.

This research is being conducted by the University of Louisville Injury Risk Assessment and Prevention (iRAP) Laboratory and Lurie Children’s Hospital (Chicago).
SUMMARY: The brain tumor glioblastoma carries a median survival time of only 12-15 months even with surgical care, radiotherapy, and chemotherapy. The aggressive spread of this cancer is complex, involving multiple routes of invasion through the dense neural architecture. Targeting glioblastoma invasion represents a promising approach to treat this disease; however, in vitro platforms that can recapitulate the neural microenvironment are lacking. The Chen Lab addresses this limitation by employing bioengineered systems that can recreate critical features of the glioblastoma tumor microenvironment and allow for more robust examination of invasion mechanisms. A few representative examples of these platforms include: hyaluronic acid hydrogels that mimic the brain extracellular matrix and tunable microchannel devices that can simulate confined migration. These systems have the potential to uncover novel mechanisms that are important in glioblastoma invasion, opening the way for a new suite of effective therapeutics for this deadly disease.

Publication: Chen J; Ananthanarayanan B; Springer K; Wolf K; Sheyman S; Tran V; Kumar S; “Suppression of LIM Kinase 1 and LIM Kinase 2 Limits Glioblastoma Invasion, Cancer Research 2020
**SUMMARY:** The objective of this work is to develop a novel, non-invasive CAD system for early detection of acute renal transplant rejection (ARTR). The proposed system integrates MRI image analysis with laboratory clinical biomarkers, as shown in following figure. Acute renal transplant rejection (ARTR), i.e., the immunological response of the human body to a foreign kidney, is the main cause of dysfunction in renal transplant patients, surpassing acute tubular necrosis and immune drug toxicity. Over 650,000 patients in the US have end-stage renal disease and renal transplant offers the best outcome for these patients. However, 15%-27% of renal transplant patients have ARTR within 5 years, which if not detected and treated promptly, causes renal damage and leads to renal failure of the transplanted kidney. Biopsy remains the gold standard for the assessment of renal transplant dysfunction but can lead to over- or under-estimation of the inflammation, and is used as a last resort due to invasiveness, high cost, and potential morbidity. The proposed study seeks to provide a new noninvasive computer-aided diagnostic (CAD) software system with the ability to make highly accurate diagnosis (>97% accuracy) at an early stage of ARTR by integrating laboratory-based biomarkers (e.g., creatinine clearance (CrCl) and serum plasma creatinine (SPCr)) with imaging-markers obtained from dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) or diffusion-weighted magnetic resonance imaging (DW-MRI).
Dr. Hermann Frieboes, Bioengineering

SUMMARY: Identification of protein biomarkers for cancer diagnosis and prognosis remains a critical unmet clinical need. A major reason is that the dynamic relationship between proliferating and necrotic cell populations during vascularized tumor growth, and the associated extra- and intra-cellular protein outflux from these populations into blood circulation remains poorly understood. Complementary to experimental efforts, mathematical approaches have been employed to effectively simulate the kinetics of detectable surface proteins (e.g., CA-125) shed into the bloodstream. We presented a new multi-compartment model to simulate heterogeneously vascularized growing tumors and the corresponding protein outflux. Model parameters can be tuned from histology data, including relative vascular volume, mean vessel diameter, and distance from vasculature to necrotic tissue. The model enables evaluating the difference in shedding rates between extra- and non-extracellular proteins from viable and necrosing cells as a function of heterogeneous vascularization. Simulation results indicate that under certain conditions it is possible for non-extracellular proteins to have superior outflux relative to extracellular proteins. This work contributes towards the goal of cancer biomarker identification by enabling simulation of protein shedding kinetics based on tumor tissue-specific characteristics.

National Research Priority: NSF 10 Understanding the Rules of Life

This research was supported by NIH/NCI Award R15CA203605. Publication: Machiraju, G., Mallick, P. Frieboes, H.B., “Multicompartment modeling of protein shedding kinetics during vascularized tumor growth,” Scientific Reports, 2020;10(1):16709.
**SUMMARY**: This work focuses on metabolomics to explore the potential to *a priori* exclude "non-responders" of certain first-line therapy treatment regimens to avoid burdening patients with ineffective treatment. Metabolomics has emerged as a method to potentially resolve the link between genotype and phenotype, giving insight into patient response. One advantage of mass spectrometry (MS) over other techniques such as nuclear magnetic resonance (NMR) spectroscopy is that MS has high sensitivity and peak capacity, especially when coupled with liquid chromatography (LC). Stable isotope resolved metabolomics (SIRM) uses stable isotope tracers (e.g. $^{13}$C, $^{18}$O and/or $^{15}$N) to yield a detailed view of cancer metabolism and enable metabolic pathway reconstruction. SIRM follows the fate of the heavy atoms and their incorporation into a multitude of metabolites produced from the labeled primary substrate, and thus quantifies heavy atom-containing metabolites, leading to exact biochemical pathway assignment. Previous cancer chemotherapy prediction models have used metabolomics data derived from other sources, such as serum or plasma samples, with the potential to detect interactions between metabolites and treatment response. In contrast, we are interested in using tumor tissue metabolites as a one-time "signature" to predict future performance. Analysis of these data with mathematical modeling as well as univariate and multivariate statistical techniques can serve to unambiguously correlate the metabolome to the treatment response and classify the patient outcomes.

National Research Priority: NSF 10 Understanding the Rules of Life

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Relative abundance of key metabolites in non-small cell lung cancer (NSCLC) disease control (DC) vs. progressive disease (PD) patient classifications. Each box represents 1st and 3rd quartiles. Bands within represent the median and x denote the mean. Ends of whiskers are maximum and minimum, with points outside being outliers. P-values found by Wilcoxon rank-sum test (p≤0.05).

This research was supported by NIH/NCI Award R15CA203605.
Dr. Hermann Friebos, Bioengineering

**SUMMARY:** Simulation of cm-scale tumor growth has generally been constrained by the computational cost to numerically solve the associated equations, with models limited to representing mm-scale or smaller tumors. While the work has proven useful to the study of small tumors and micro-metastases, a biologically-relevant simulation of cm-scale masses as would be typically detected and treated in patients has remained an elusive goal. This study presents a distributed computing (parallelized) implementation of a mixture model of tumor growth to simulate 3D cm-scale vascularized tissue at sub-mm resolution. The numerical solving scheme utilizes a two-stage parallelization framework. The solution is written for GPU computation using the CUDA framework, which handles all Multigrid-related computations. Message Passing Interface (MPI) handles distribution of information across multiple processes, freeing the program from RAM and the processing limitations found on single systems. On each system, Nvidia’s CUDA library allows for fast processing of model data using GPU-bound computing on fewer systems. The results show that a combined MPI-CUDA implementation enables the continuum modeling of cm-scale tumors at reasonable computational cost. Further work to calibrate model parameters to particular tumor conditions could enable simulation of patient-specific tumors for clinical application.

National Research Priority: NSF 10 Understanding the Rules of Life
SUMMARY: Tumor associated macrophages (TAMs) have been shown to both aid and hinder tumor growth, with patient outcomes potentially hinging on the proportion of M1, pro-inflammatory/growth-inhibiting, to M2, growth-supporting, phenotypes. Strategies to stimulate tumor regression by promoting polarization to M1 are a novel approach that harnesses the immune system to enhance therapeutic outcomes, including chemotherapy. It was recently discovered that nanotherapy with mesoporous particles loaded with albumin-bound paclitaxel (MSV-nab-PTX) promotes macrophage polarization towards M1 in breast cancer liver metastases (BCLM). However, it remains unclear to what extent tumor regression can be maximized based on modulation of the macrophage phenotype, especially for poorly perfused tumors such as BCLM. This study implements a mathematical framework to evaluate nanoparticle-mediated chemotherapy in conjunction with TAM polarization. The response is predicted to be not linearly dependent on the M1:M2 ratio. To investigate this phenomenon, the response is simulated via the model for a variety of M1:M2 ratios. The modeling indicates that polarization to an all-M1 population may be less effective than a combination of both M1 and M2. This model-driven hypothesis was confirmed by experimental work using a CRISPR system that permanently modulates macrophage polarization in a controlled in vitro setting mimicking the BCLM hypovascularized environment with various ratios of polarized macrophages. Altogether, this study indicates that response to nanoparticle-mediated chemotherapy targeting poorly perfused tumors may benefit from a fine-tuned M1:M2 ratio that maintains both phenotypes in the tumor microenvironment during treatment.

This research was supported by NIH/NCI Award R15CA203605

Dr. Steven Koenig, Bioengineering

SUMMARY:
The Advanced Heart Failure Research (AHFR) program is a multidisciplinary team of clinicians, engineers, and scientists that conducts pre-clinical research and development of novel medical devices and pioneering therapies with translation into clinical practice for the treatment of cardiovascular, pulmonary, and neurological diseases in collaboration with industry sponsors. The following feasibility projects were awarded, prototypes fabricated, and testing initiated:

- Wireless power and communication of neuro-stimulation electrodes for treatment of Parkinson’s disease (Figure 1A)
- Wireless power and communication with left ventricular assist device for treatment of advanced heart failure (Figure 1B)
- Wireless power and communication with a bi-ventricular pacing lead for treatment of advanced heart failure (Figure 1C)
- Intravascular device that provides circulatory support for treatment of high risk protected coronary intervention and cardiogenic shock (Figure 1D)
- Partial occlusion device CardiAction to facilitate minimally invasive surgery for implant of mechanical circulatory support devices (Figure 1E)

Steven C Koenig, PhD Professor and Endowed Chair Bioengineering and Cardiothoracic Surgery, University of Louisville

Our pre-clinical research and development is conducted in Cardiovascular Innovation Institute (CII) in vitro and in vivo labs

Projects are supported by 5 NIH SBIR phase I grants (R43NS115226-01-01, R43HL152767-01, R43HL149451-01, R43HL152774-01, R43HL144214-01)
Summary: This work focuses on developing an innovative platform technology for highly efficient intracellular delivery of molecules by integrating ultrasound and microfluidics. A major focus of this project is to deliver protective compounds to red blood cells (RBCs) in order to enable dry preservation of blood at ambient temperatures for long periods. There is currently no method that is safe and cost-effective enough for routine long-term preservation of RBCs. Therefore, an effective method to preserve RBCs in a dried state for long-term storage at ambient temperatures would solve the blood supply challenges that frequently occur. In addition, this platform technology could also be used for other applications, including dry preservation of other cells types, and high-precision non-viral transfection for CAR T and other immunotherapies.
DNA Aptamer-Coated Cancer-targeting Gold Nanoparticles

Dr. Martin O’Toole, Bioengineering

**SUMMARY:** Aptamer-coated nanoparticles are a promising tool for targeted cancer diagnosis and therapy. Our lab has partnered with the Brown Cancer Center and Qualigen, Inc. to develop and optimize gold nanoparticles (GNP) that have been decorated with DNA aptamer AS1411, which has known cancer targeting and therapeutic capabilities. We have optimized synthesis methods that allow us to produce large quantities of GNP-AS1411 with a variety of formula variations for testing in in vitro and in vivo models of cancer. Once we have determined the best candidate formulation, we will assist Qualigen, Inc in beginning Phase I clinical trials for testing our nanoparticles in cancer patients. Additionally, we are working to expand the clinical capabilities of the nanoparticles to selectively deliver chemotherapy agents and imaging agents to tumors.

National Research Priority: Nanoscale Science and Engineering

This research used the core facilities at the University of Louisville Conn Center and the MicroNanoTechnology Center and was supported by the University of Louisville Coulter Translational Fellowship and an industry contract with Qualigen, Inc. Publication: Malik, M. T.; O’Toole, M. G.; Casson, L. K.; Thomas, S. D.; Bardi, G. T.; Reyes-Reyes, E. M.; Ng, C. K.; Kang, K. A.; Bates, P. J., AS1411-conjugated gold nanospheres and their potential for breast cancer therapy. Oncotarget 2015, 6 (26), 22270.
Dr. Tommy Roussel, Bioengineering

**SUMMARY:** NASA has outlined an ambitious plan for human travel back to the moon and eventually to Mars. Extended space travel requires consideration of the possibility of the need to perform surgery in zero gravity, which poses many unique challenges. In response to NASA requests for surgical automated technology to support surgery in zero gravity, Dr. Tommy Roussel (Bioengineering) and Dr. George Pantalos (CII), along with collaborators at Carnegie Mellon and Cornell University are developing an aqueous immersion surgical system (AISS) for deployment on manned parabolic flights (ZeroG) that simulate zero gravity, as well as unmanned (automated) flights on Space Ship 2 (Virgin Galactic) which will pass into true zero gravity beyond the Karman Line. The system contains a surgical containment dome to isolate and contain a bleeding wound, integrated leak-free ports to pass surgical instruments, and a variety of pumps, valves, pressure and flow sensors to control filling, emptying, suction and irrigation functions via a custom multifunctional surgical device, design for either manual or automated control. The system and surgical simulation protocol will be evaluate in February 2021.

National Research Priority: NASA Space Technology Roadmap Section TA06 - Human Health, Life Support and Habitation Systems, Technology Area Strategic Road Map, Area 6, Section 2.3 (Human Health and Performance):

…medical assist robotics for laparoscopic surgery and a surgical suite with sterile, closed-loop fluid and ventilation systems for trauma and other surgeries

This research is supported by the NASA Flight Opportunities Program Payload T0155-S | Publication: B. Barrow, G. Pantalos, T. Roussel, “Design of a 3D printed Endoscopic Multifunction Surgical Device”. Astra Astronautica. DOI 10.1016/j.actaastro.2020.05.037. April 2020
SUMMARY: The inability to maintain upright posture is a major consequence of spinal cord injury (SCI). For children with SCI, skeletal immaturity and musculoskeletal growth increase the risk for scoliosis. Existing physical rehabilitation focuses on management or compensation for paralysis of trunk muscles, but recent work has shown that children with SCI can respond to locomotor training (LT) to improve trunk control. These findings reset expectations for rehabilitation in children with SCI, but there is need to promote improved trunk control at home and to monitor progress in clinical and research settings. The simple activity of rocking promotes successful self-initiated movements by children who have limited capacity to move and engage in their environment, complements the clinical activity-based therapy, and allows a home-based, age-appropriate, and accessible activity encouraging repetitive activation of trunk muscles. Supplemental practice time reinforces the therapeutic activity and also increases motivation to perform. In addition to providing patients with the opportunity to move in beneficial ways, the rocking activity creates a unique opportunity to incorporate instrumentation that can be used to assess biomechanical movements associated with the activity (speed of rocking, forces used to initiate and maintain rocking, etc.) and a novel technique that can be used to quantify patient gains in trunk control. Dr. Tommy Roussel (Bioengineering) along with Dr. Andrea Behrman (Frazier Rehab) are developing a custom rocking chair design to allow children to rock safely and enable activation of trunk muscles in an enjoyable activity. In addition, instrumentation on the chair will allow therapists to track chair use, and to identify muscle use patterns and potentially quantify trunk control.

Dr. Tommy Roussel, Bioengineering

This work was funded through the generous support of the Todd Crawford Foundation to Cure Paralysis, the NSF UofL I Corps Program, and NSF EPSCoR RII Track 1 Kentucky Advanced Manufacturing Partnership for Enhanced Robotics and Structures (Award 1849213) | Publication: J. George, A. Behrman, T. Roussel, “Design of a Smart Rocking Chair for Children with Spinal Cord Injury Using a Quality Function Deployment Design Methodology” 2020 BMES Annual Meeting
Development of a Power-Compensated MEMS DSC Sensor for Detection of Myocardial Infarction Type

Dr. Tommy Roussel, Bioengineering

SUMMARY: Differential Scanning Calorimetry (DSC) is an established biophysical technique that measures subtle changes in heat capacity associated with the thermal denaturation of biomolecules. A growing number of studies have shown that DSC profiles (thermograms) are successfully at differentiating healthy individuals from those with various diseases, including cancers and autoimmune diseases. Dr. Tommy Roussel along with collaborators Dr. Nichola Garbett (Brown Cancer Center) and Dr. Andrew DeFilippis (Vanderbilt University Medical Center) are developing a power-compensated microfabricated DSC platform using thin-film heaters, which act as highly sensitive temperature sensors to reduce the complexity of the sensor design and enable calorimetry of biological materials. The goal of the research is to create a differential scanning calorimetry system for rapid identification and differentiation of specific causes of heart damage, including the different types of myocardial infarction (heart attack) which will lead to point-of-care diagnosis of myocardial infarction and myocardial infarction sub-types. To date, the research has produced a first-generation reduced complexity MEMS DSC sensor shown to be sensitive enough to detect the thermal denaturation of lysozyme protein at a concentration normally used on commercial DSC instruments. With continued support from the KYNETIC program, continuing development will include fully characterizing the sensors with DSC temperature and enthalpy standards, phosphocholine lipids and lysozyme, respectively, along with human plasma proteins, and eventually samples of whole blood.

This research used the core facilities at the University of Louisville Conn Center and the MicroNanoTechnology Center. This work was funded by the National Institutes of Health U01 HL152392 KYNETIC Program Pilot Project Title: Development of a Differential Scanning Calorimetry System for Rapid Identification and Differentiation of Specific Causes of Heart Damage—including Different Types of Myocardial Infarction—and NIH U01 HL127518 ExCITE Pilot Project Title: Point-of-Care Differential Scanning Calorimeter for Diagnosis of Myocardial Infarction and Myocardial Infarction Sub-types. Publication: A. Melvin, A. Kaliappan, G. Schneider, A. DeFilippis, N. Garbett, T. Roussel, "Development of a Power Compensated MEMS DSC Sensor," 2020 BMES Annual Meeting.
Dr. Patricia Soucy, Bioengineering

**SUMMARY:** Mechanical stimuli have previously been shown to alter cellular activities in many cell types and tissues. Dr. Soucy's research in collaboration with Dr. Shigeo Tamiya (UofL's Department of Ophthalmology) examines the role of scaffold stiffness in directing cell differentiation leading to the development of proliferative vitreoretinopathy, a fibrotic complication involving the formation and contraction of scar tissue on the retina. Dr. Soucy's research team focuses on the development of scaffolds with different stiffnesses to be utilized for cell culture studies. These in vitro studies aim to identify key cell signaling molecules involved in proliferative vitreoretinopathy. Her team quantifies the scaffold's mechanical properties and measures the mechanical properties of tissues and tissue models created in vitro. This work addresses proliferative vitreoretinopathy, a significant clinical problem with loss of visual acuity, and in severe cases blindness. Identifying key molecules and signals involved in the development of this condition has the potential to uncover key molecular therapeutic targets for prevention of proliferative vitreoretinopathy, and possibly other fibrotic diseases.

This research used the core facilities at the University of Louisville MicroNanoTechnology Center and was supported by National Eye Institute, NIH Award # R01EY030060.
Dr. Jill Steinbach-Rankins, Bioengineering

**SUMMARY:** The Steinbach-Rankins lab is focused on developing nanoparticle, fiber, and 3D printed delivery vehicles against viral and bacterial infections. Periodontal disease involves the inflammation of tooth-supporting structures, caused by dental plaque, leading to the destruction of periodontal ligament and bone. *Porphyromonas gingivalis* adherence to *Streptococcus gordonii* is a crucial initial event that facilitates the colonization of *P. gingivalis*, a key pathogen in periodontal disease. As such, blocking these early interactions may present a potential avenue to limit *P. gingivalis* colonization. Nanoparticles encapsulating a synthetic peptide (referred to as BAR) inhibit *P. gingivalis/S. gordonii* biofilm formation more potently than free BAR. However, BAR-encapsulated NPs, like many orally delivered formulations, may benefit from a strategy that improves their retention in an open flow environment.

Here, we sought to enhance the efficacy of BAR-encapsulated NPs by modifying their surfaces with coaggregation factor A (CafA), a fimbrial protein expressed by the early colonizer, *Actinomyces oris*. We demonstrated that the targeting moiety, CafA, enhances NP binding and exhibits specificity of adherence to *S. gordonii*, relative to other oral bacterial species. Furthermore, CafA-modified NPs release inhibitory concentrations of BAR for 12 h, a time frame relevant to oral delivery. Lastly, CafA-modified NPs potently inhibit *P. gingivalis/S. gordonii* biofilm formation for up to 12 h and are non-toxic at therapeutically-relevant concentrations. These results suggest that CafA-modified NPs represent a novel and efficacious delivery vehicle for localized, targeted delivery of BAR to *P. gingivalis* preferred niches.

New Delivery Vehicles for Female Reproductive Health

Dr. Jill Steinbach-Rankins, Bioengineering

SUMMARY: The Steinbach-Rankins lab is focused on developing new delivery vehicles, in the forms of fibers, 3D printed scaffolds, and nanoparticles against female reproductive viral and bacterial infections. To date, we have developed fibers that incorporate and are surface-modified with antiviral drugs and biologic active agents to decrease virus (HSV-2 and HIV-1) inoculum at entry. To target virus that has entered cells, we have developed fibers that incorporate and prolong the delivery of well-established antivirals. In addition, we have developed pH-responsive polymeric fibers to release biological active agents upon activation.

For bacterial-specific infections, we are currently investigating the ability of sequentially-layered and dual-spun fibers to viably deliver probiotics known to stabilize the vaginal microbiota. In parallel we have applied 3D bioprinting to explore how scaffolds may also modulate the female reproductive environment. We seek to test these new platforms for the inhibition of bacterial vaginosis (BV) that plagues approximately 1/3 of women at any given time. We are enthusiastic to merge our expertise to study host, microbe, and delivery vehicle interactions to better inform platform design for clinical application.

This research has been supported by NIH Awards: R01AI139671 and P20GM125504 and by the Jewish Heritage Fund for Excellence grant and competitive enhancement grant.
SUMMARY: Hip fractures occur frequently in the aging population and have devastating health, social, and economic consequences. Between 25 and 30% of patients die within one year of their hip fracture and the medical costs approach $18B annually in the US. Research in the Orthopaedic Bioengineering Lab has shown that the specific loading pattern of the fall-to-the-side mechanism that accounts for over 90% of hip fractures can be exploited by a targeted exercise designed to stimulate the natural bone remodeling response in order to strengthen the proximal femur of vulnerable patients and lead to a viable non-pharmacological fracture prevention strategy. A combination of high-resolution finite element computer simulation models together with biomechanical testing of cadaver femurs has lead to a prototype exercise device with instrumentation that enables the user to control their therapy to optimally stimulate their own bone cells to increase the bone density in the critical part of their skeleton. Funding is currently being sought to support safety (in vitro cadaver experiments) and efficacy (in vivo human trials) studies. Two Master’s degree students and one Ph.D. student have contributed to this research.

This research used the core facilities at the University of Louisville Conn Center and the MicroNanoTechnology Center and was supported by NSF Award # NSF IIP 1450730. Publication: Sudan, K.; Singh, P.; Gökçe, A.; Balla, V. K.; Kate, K. H., “Processing of hydroxyapatite and its composites using ceramic fused filament fabrication (CF3)” Ceramics International 2020.
Chemical Engineering
Dr. Willing, Chair

The Chemical Engineering program focuses on harnessing fundamental discipline concepts like thermodynamics and transport processes in a wide variety of application areas. Research in the discipline is, by its very nature, diverse and multidisciplinary and involves interactions with numerous groups both within and outside of the department.

**Vision for Research** The Chemical Engineering Department has a strong core competency in materials research focused on the chemistry of materials and materials degradation. Over the next several years, we will continue to develop our emerging competencies in biochemical engineering and computational science. Our goal is to directly apply these competencies to existing and newly identified areas of need for our campus, industrial, and community partners.

**Top Areas of Research**
- Chemistry of Materials and Materials Degradation
- Bioprocessing for Sustainability
- Computational Chemistry for Materials and Process Development
- MEMS Technologies for Non-Invasive Disease Detection
- Computational Fluid Dynamics for Modeling of Physiological Process
- Materials Processing in Additive Manufacturing
SUMMARY: One million invasive coronary angiography procedures are performed every year in patients who present with chest pain or are known to have stable coronary artery disease. The goal of the procedure is to determine if there is a significant stenosis that limits blood flow to the heart muscle. The cardiologist determines the significance of the stenosis by invasively measuring fractional flow reserve (i-FFR), which is the Gold Standard test that. However, i-FFR is invasive, uncomfortable for patients, expensive, time-consuming, and requires radiation and contrast exposure. We combine computational fluid dynamic modeling with patient-specific imaging of the arteries provided by Cardiologists in the University of Louisville Department of Medicine to characterize altered blood flow dynamics in and around stenotic regions that is indicative of physiologically significant stenosis. By characterizing in terms of fluid dynamics, transport, and mixing concepts, i-FFR can be replaced with a cutting edge non-invasive diagnostic method. Our new computational metric was computed for 100 patients and agreed with i-FFR in 97 of the cases. Model sensitivity and specificity for diagnosis of hemodynamically significant coronary stenosis was 98% and 96%, respectively, compared with i-FFR.
Dr. Joel Fried, Chemical Engineering

**SUMMARY:** Polymeric membranes formed from diblock or more commonly triblock copolymers of hydrophilic and hydrophobic polymeric segments have been found to mimic biological and synthetic lipid membranes. These membranes either in flat membranes or vesicles (polymersomes) can incorporate a large number of membrane proteins such as gramicidin and alamethicin as shown by electrophysiological measurements in our lab and reviewed in our Langmuir publication. These membrane proteins function as channels as they would in lipid membrane structures even though the biomimetic membranes can be twice the thickness of a lipid membrane. We are currently working on molecular simulations to understand how these membrane proteins organize in the biomimetic membranes. We have completed preliminary atomistic simulations of the diblock and triblock polymers and will develop coarse-grain simulation protocols that can be used to study self-assembly of the block copolymers and the process of protein insertion and organization. Planned are EPR studies of spin-labelled gramicidin inside a biomimetic membrane that can be used to validate the simulation studies. Potential applications for these biomimetic systems include such diverse areas as sensors, nanoreactors, ATP generation, DNA sequencing, and water treatment.

On the left is a microscope image of a formed biomimetic membrane of a triblock copolymer with a diameter of 120 microns. On the right is a drawing of a cross section of the cell wall incorporation a gramicidin protein transporting potassium cations that is measured by electrophysiological measurement of conductance.

This research was made possible by work of research associate Mike Martin and ChE PhD student Tim Dubbs. Publication: Martin, Michel; Dubbs, Timothy; Fried, J. R. “Planar Bilayer Measurements of Alamethicin and Reconstituted in Biomimetic Block Copolymers,” *Langmuir* 2017, 33, 1171-1179.
Dr. Xiao An Fu, Chemical Engineering

**SUMMARY:** The goal of this work is to develop thiol functionalized gold nanoparticle microsensor array platform for the detection of toxic volatile organic compounds (VOCs) in environmental air. Exposure to toxic VOCs may cause serious health issues. The sensor array features microfabricated inter-digited electrodes (IDEs) and designed thiols for functionalization of gold nanoparticles to detect target VOCs through physical adsorption. The interaction between specific thiol on the surfaces of gold nanoparticles and target VOC induces significant conductivity change of the thin film of thiol functionalized gold nanoparticles. Each thiol was designed to enhance interaction with a target VOC to increase both sensitivity and selectivity. The sensor array on the chip provide selective detection of different target compounds. A combination of IDEs and specific thiol functionalized gold nanoparticles enables detection of target VOCs in environmental air.

X.A. Fu and M.H. Nantz, Chemical Engineering, Chemistry, University of Louisville. Work performed at University of Louisville. This work was supported by NIH Award # 5 P42ES023716. RSC Advances 2018,8,35618-35624.
**Molecular Mechanisms of Electroporation from Computational Electrophysiology**

**Dr. Vance Jaeger, Chemical Engineering**

**SUMMARY:** Electroporation (EP) is a method by which exogeneous DNA can be introduced to a cell by applying a pore-inducing voltage across the cell membrane. EP is commonly applied for genetic engineering. Even with state-of-the-art experimental techniques, pore structures cannot be probed with the temporal and spatial resolution needed to elucidate the driving forces behind pore formation and stability. The Jaeger Lab employs a novel simulation technique known as Computational Electrophysiology to generate simulated molecular structures of biological membranes under a range of stresses. Our results indicate that pore morphology and molecular transport is driven primarily by the strength of the applied electric field rather than the electrical potential. These insights will be used to design improved EP protocols to maximize gene transfer while minimizing cell mortality.

National Research Priority: NSF 10 Big Ideas on Harnessing the Data Revolution

Simulated structures of pores through cell membranes. On the left is the electric potential. On the right is the electric field. The balance of forces within the membrane allows the pore to remain stable for extended periods so that DNA and other molecules can pass into the cell.

This research used the University’s Cardinal Research Cluster and was supported by UofL startup funds.


“Dissecting Electric Field Components of Membrane Stability”. Brian J.P. and Jaeger V.W. (In Preparation)

*Software:* https://github.com/JPatrickBrian
Toward a Circular Economy of Plastic and Biomass Waste by Chemical Upcycling

Dr. Noppadon Sathitsuksanoh, Chemical Engineering

SUMMARY: To mitigate plastic pollution and greenhouse gas emission, we need to develop chemical upcycling process to transform plastic and biomass waste into valuable chemicals and/or devices. Our current research aims to:

1. Develop a hybrid chemical and biological transformation of plastic waste products to biodegradable polymers for packaging and coating applications,
2. Identify the catalytic systems to upgrade plant biomass to renewable chemicals and energy storage devices.

This research used the core facilities at the University of Louisville Conn Center.

Publication:
High-Performance Stainless Steel Powder for Selective Laser Melting Additive Manufacturing

Dr. Thomas Starr, Chemical Engineering

**SUMMARY:** This project aims to design and develop a new powder for high-strength martensitic precipitation-hardenable (PH) stainless steel that is optimized for the unique processing conditions and challenges of selective laser melting (SLM) additive manufacturing (AM). A key objective is to achieve lower cost by eliminating or significantly reducing post-build heat treatment steps. Powder design utilizes an integrated computational materials engineering (ICME) framework. Experimental validation of the alloy design includes optimization of the SLM process parameters, microstructure/phase characterization of fabricated parts and mechanical testing. The project is a partnership between the University of Louisville and QuesTek Innovations LLC. With lower cost, reliable processing and enhance performance the optimized stainless steel powder will be used for naval aviation components.

Small variation of Cr and Ni content leads to dramatic differences in as-built phase composition. Modeling relates this to change in ferrite-to-austenite transition temperature and rapid cooling that is characteristic of the SLM process. Longer cooling time in the ferrite instability range (T4 → T2) results in less residual ferrite.

This project used the facilities of the Additive Manufacturing Institute of Science and Technology (AMIST) and the Conn Center for Renewable Energy Research and is supported by The U.S Naval Air Systems Command (NAVAIR) contract N68335-18-C-0020.
SUMMARY: Cross-linked polymeric materials, such as styrene-butadiene rubber (SBR), are some of the most difficult polymeric waste streams to contend with due to the diversity and stability of the materials involved. Additionally, the amount of material that is generated annually from these streams borders on the incomprehensible. In 2015, it was estimated that 1 billion tires were being scrapped annually worldwide and that nearly one-third of those tires were discarded into landfills. While waste tires are a significant portion of the cross-linked materials waste stream, these wastes span everything from the traditional rubber materials, including natural and styrene-butadiene rubber, to more modern rubbers such as ethylene propylene diene monomer (EPDM) rubber, and even the new cross-linked thermoplastics such as cross-linked polyethylene (PEX). Current methods to reduce the amount of waste from these materials come in two forms. First, the waste materials can be ground up and included in other materials or used on their own. Second, they can be burned for energy value. Neither of these processes is particularly attractive from an environmental or value-added perspective. We have developed a process that can break down cross-linked rubber materials using a low-temperature, low-pressure process similar to that used to produce potable water.


Stages of the rubber recycling process starting from pulverized rubber (top) going through the aqueous process (middle) which leads to the recovery of the elastomers (bottom) that can be vulcanized back into rubber.

This research was conducted in the Complex Fluids and Directed Self-Assembly Laboratory and used the core facilities at the University of Louisville Conn Center.
Developing Colloidal Crystals for New Optical Applications

Dr. Gerold Willing, Chemical Engineering

**SUMMARY:** Colloidal crystals are being developed for a number of applications, including quantum dot sensitized solar cells, optical computing, and optical switching, due to their unique optical properties that arise from their highly ordered structure. One of the critical research areas is developing crystals that contain particles of different sizes and materials so that optical properties can be specifically tailored. Towards this end, we are utilizing a new colloidal system known as Nanoparticle Haloing (NPH) which is a suspension with a bimodal particle size and charge distribution as a basis for new crystal structures. In order to determine how the crystallization process begins and what kind of structures can be formed, we with NASA to conduct crystallization experiments in the Light Microscopy Module (LMM) on board the International Space Station. This project is both multidisciplinary involving researchers in Chemical Engineering, Mechanical Engineering, and Chemistry and highly collaborative through the involvement of engineers and scientists from NASA and Zin Technologies, the company that designed and built the LMM.

Funded by NASA EPScR NNX14AN28A “Influence of gravity on electrokinetic and electrochemical colloidal self-assembly for future materials” SJ Williams, GA Willing, H Rathnayaki

Capillary sample holder (top left) with NPH samples that were used in the LMM (top center) on board the International Space Station during experiments in spring of 2021. Dr. Willing and our students interact heavily with scientists and engineers from NASA and Zin Technologies (top right). Images from the LMM (bottom left) contain a lot of data that requires new analysis tools (bottom middle) like the colloidspy package to help identify possible crystal structures (bottom right) in the images.

This research was conducted in the Complex Fluids and Directed Self-Assembly Laboratory and the Integrated Microfluidic Systems Laboratory. Core facilities at the University of Louisville Conn Center and the Micro/Nano Technology Center.
Civil and Environmental Engineering
Civil and Environmental Engineering

Dr. Sun, Chair

The Department of Civil and Environmental Engineering (CEE) prepares students for careers that solidify our infrastructure and protect the natural world. Department faculty are focused on research to improve and extend the life of the built environment as well as maintain healthy natural systems. By developing more sustainable and resilient designs, we can improve both the environment and the economic condition of our state and nation.

Vision for Research Civil and Environmental Engineering research is focused on advances in design, construction, safety, maintenance, operations, and management of the natural and built environment. By promoting interdisciplinary research, the CEE faculty use state-of-the-art knowledge to build green and smart systems with innovative materials, clean energy, artificial intelligence, and ecological solutions.

Top Areas of Research.

• Energy efficiency and renewable energy for building infrastructure systems
• Smart cities and intelligent transportation systems
• Urban stormwater control and stream/wetland restoration
• Reuse of industrial wastes for recovery, rebuilding, and rehabilitation
**SUMMARY:** In recent decades, increased utility of deep geothermal energy, ground source heat pumps (GSHP), and nuclear waste disposal, which is a product of nuclear power plants, bring about the necessity for research to be done on soil thermo-mechanical behavior under different temperatures. There are also other applications for this research, such as building infrastructures in permafrost areas or underground structures close to thermal (heat) disturbances discharged from facilities and systems. This research project will fundamentally investigate the interactions of temperature, pore fluid flow, volumetric changes, and excess pore pressure generations in different soil media (clay, sand). Temperature gradient and heat transfer in saturated porous media may affect pore fluid pressure and/or pore fluid flow depending on thermal, mechanical, and hydraulic properties of the media and the saturating fluid. On the other hand, temperature gradient in unsaturated media results in soil drying, phase change, and liquid and vapor flow in the medium. Dr. Ghasemi-Fare’s research team is integrating numerical and experimental models to explore the thermo-hydro-mechanical behavior of different soils.

Identification of Structural System using Bayesian Model Updating

Dr. Young Hoon Kim, Civil and Environmental Engineering

**SUMMARY**: Dynamic motions are useful data for bridge conditions. The research team wants to use the structure's vibrational behavior for structural health assessment. Recently, the Bayesian model updating approach (BMUA) has been widely used to update structural parameters using modal measurements because of its powerful ability to handle uncertainties and incomplete data. However, a conventional Bayesian model updating approach (BMUA) is mainly used to update stiffness with the assumption that structural mass is known. Because simultaneously updating stiffness and mass lead to unidentifiable case or coupling effect of stiffness and mass, this assumption in conventional BMUA is questionable to update stiffness when the mass has significantly changed. This study proposes a new updating framework based on two structural systems: original and modified systems. The proposed approach can provide a new engineering tool for structural engineers to identify the damages in the target structure.

Dr. Robert Kluger, Civil and Environmental Engineering

**SUMMARY:** Crashes are one of the leading causes of preventable death in the United States, carrying a severe burden on public health and wellness. Police-reported crash data is the primary source of information for transportation engineers to systematically address safety. However, there exist other additional datasets that can help explain factors associated with variance in crash outcomes and dictate how safety is addressed. Recent research at the University of Louisville has linked four datasets within Jefferson County, including crash data from the state police, EMS run data from Louisville Metro Government's computer-aided dispatch system, patient care reports collected by paramedics and EMTs at the scene of the crash, and trauma registry data from UofL Hospital. Emergency Medical Services (EMS) and Hospitals both collect data about victims of traffic injuries. Both include specifics of the injury through diagnoses and narratives. The objective of the project is to build upon the framework developed and adapt the linkage approach to statewide using data from the Kentucky State Police, Kentucky Board of EMS, and KIPRC. While the statewide data is more far reaching, the primary challenge will be determining how to adapt to differences in data completeness within the EMS and trauma datasets, since the datasets are sourced from numerous agencies across the state.
Dr. Richard Li, Civil Engineering (Transportation)

**SUMMARY**: The emerging connected and automated vehicles will be a game changer in our transportation system. Dr. Li’s research leverages the emerging technologies to enhance the urban and rural transportation mobility and safety. A next-generation interchange control (NIC) of connected and autonomous vehicles at freeway interchange ramp terminals was developed. A centralized control algorithm was used to minimize the delay at interchange and maximize the throughput of traffic, and minimize the emission and energy consumption from vehicles. Kentucky has the potential to transform the future of transportation with the implementation of Automated Vehicle (AV) technology. A research project has been carried to assess, model, and evaluate driver’s behaviors with different levels of driving automation in driving simulation. Safety issues under driving automation levels 2 through 4 are to be identified, and potential safety improvement was quantified.

National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier
Dr. Tyler Mahoney, Civil and Environmental Engineering

SUMMARY: Ecosystem health and water resources are directly impacted by the source, fate, and transport of point and non-point source pollutants within watersheds. A deep understanding of the hydrologic processes impacting transport of such pollutants is critical to their management. Dr. Tyler Mahoney’s research utilizes watershed-scale hydrologic models, high-frequency water quality sensing technology, and stable isotope tracers to improve understanding of hydrologic controls impacting such transport phenomena. As an example, Dr. Mahoney has investigated streamflow permanence and stream expansion/contraction using process-based models and high temporal frequency flow state sensors. This work has important implications on the federal protection of water ways in the United States. Dr. Mahoney has also focused on quantifying watershed-scale sediment transport and connectivity using models, sensors, and sediment fingerprinting techniques with stable isotopes. This research has assisted with management of excessive sedimentation, which is one of the leading causes of stream impairment in Kentucky.

National Research Priority: NSF 10 Big Ideas on Understanding the Rules of Life

Dr. W. Mark McGinley, Civil and Environmental Engineering

**SUMMARY:**

**WHAT IS THE PROBLEM?**

Intensive use of energy (5Gj/t) is the significant portion of the cost of manufacturing cement, excluding the environmental impact from its production. Incorporating modern monitoring, simulation and control systems can make the industry more efficient monetarily and environmentally.

**WHAT IS THE TECHNICAL APPROACH?**

Lab and rotary cement kilns will be used as test beds to develop a sensor suite, predictive models and control system logic to characterize the product stream in the kilns. Additional systems states such as mass and air flow(s), along with rotational velocity will also be used to control the Kiln for optimal production quality and energy consumption using real-time predictive control. The goal is to reduce energy use by at least 15%

National Research Priority: Smart Manufacturing

Dr. W. Mark McGinley, Project Lead, Civil and Environmental Engineering, University of Louisville, Dr. Mahendra Sunkara, Thad Druffel and Dr. W. Paxton, Conn Center, Dr. Michael McIntyre, Dr. Ali Farag and Dr. Asem Ali, Electrical and Computer Engineering

This research used the core facilities at the University of Louisville Speed School and the Conn Center supported by CESMII/DOE Award # DE-EE 0007613.
Dr. Tom Rockaway, Civil and Environmental Engineering

**SUMMARY:** Communities across the country are coping with the adverse impacts of stormwater runoff. In response, many have started implementing large-scale Green Stormwater Infrastructure (GSI) solutions such as permeable pavements, bio-swales, and planter boxes to mitigate stormwater runoff by utilities to address this growing challenge. Quantify the long-term performance of GSI solutions is critical for utility managers. Locally the Center for Infrastructure Research at the University of Louisville has worked with the Louisville Metropolitan Sewer Authority to monitor and model the long-term performance of install GSI practices. Specifically, the study conducts an initial assessment of the hydrological performance and pollutant removal efficiency of a permeable pavement system with an underlying infiltration trench. To quantify the hydrological performance of the GSI, the study used embedded piezometers to model the water levels within the practice. The study compared a finite number of grab samples of surface stormwater runoff and captured stormwater obtained from the bottom of the infiltration trench to quantify the pollutant removal efficiency. Modeling of the hydrologic performance showed that GSI control maintains 60% of its initial infiltration capacity from the installation date and captured 70% of the runoff from its contributing watershed. The water quality analysis indicated the GSI served as an effective pollutant removal mechanism, significantly reducing the E. coli (60.7%) and TSS (43.5%) concentrations between the stormwater runoff and captured volume samples.

**Cross-Section of the Permeable Pavement System 17G (image source MSD)**

This research used the core facilities at the University of Louisville’s Center for Infrastructure Research and was supported by the Louisville Metropolitan Sewer District. Publication: Rockaway, T.; Kazemi, H.; Rivard, J.; Abdollahian, S. “Assessment of Surface Infiltration Performance and Maintenance of Two Permeable Pavement Systems in Louisville, Kentucky”, Journal of Sustainable Water in Built Environment, 3(4).
A Green Concrete Pavement with Water Purifying Functions

Dr. Zhihui Sun, Civil and Environmental Engineering

SUMMARY: Groundwater quality is essential for drinking water supply, geotechnical engineering, and sustainable development. With the expansion of the metropolitan areas, stormwater runoff from road system, parking lots and open spaces becomes one of the major contaminant sources to the groundwater. Among various runoff contaminants, Polycyclic Aromatic Hydrocarbon (PAHs) is a significantly cumulative cancerogenic component that is health threatening. PAHs is largely released from the vehicle emission, oil leakage and tire wear. Therefore, mitigation PAHs contamination from stormwater runoff adjacent to transportation corridors becomes extremely important. For groundwater protection, the Best Manage Practices (BMPs) suggests using filler materials such as zeolite, sand, limestone, zero valent irons, etc. However, these natural sorbents have relatively lower efficiency for remediating the organic contaminant (such as PAHs that arise cancer risks) due to the hydrophilic surface properties. Meanwhile, our current infrastructure is aging and needs extensive reconstruction. Innovative construction materials, e.g. multi-functional paving materials, are in urgent demand to not only meet the design criteria but also address the issues related to environmental impact. This leads to the goal of this research, which is to develop a multi-functional green concrete (MGPC) with in-situ remediation function to mitigate groundwater contamination caused by PAHs in stormwater runoff adjacent to transportation corridors.

Conn Center for Renewable Energy Research
Dr. Thad Druffel, Conn Center

**SUMMARY:** This work targets the scalability of the deposition of two solution phase films for the high speed manufacture of perovskite solar cells. These films include a water-based tin-oxide nanoparticle dispersion at 50 nm thick and a metal-organic halide at 500 nm thick. Both films are deposited at 2.5 m/min using a slot die followed by an annealing step using Intense Pulsed Light (IPL). The IPL lamp source is tuned to flash every 0.5 seconds for 100 microseconds. The resulting devices produce large-area (> 1cm²) solar cells on plastic with a device efficiency of ~10 percent. The IPL process effectively reduces the footprint for the roll-to-roll manufacturing line by several orders of magnitude. This demonstration of the nano to meter scale manufacturing will be scaled to upwards of 10 m/min.


(a) Picture of Roll-to-roll processed flexible perovskite devices manufactured at 2.5 m/min producing large area cells, (b) SEM of perovskite grains and (c) XRD of perovskite film.

Siva Pakanati, Blake Martin, Sashil Chapagain, Peter Armstrong, Craig Grapperhaus and Thad Druffel, Conn Center for Renewable Energy Research, Speed School of Engineering, College of Arts and Sciences, University of Louisville. Work performed at University of Louisville’s Conn Center for Renewable Energy Research. This work is funded by the U.S. Department of Energy (DoE) solar energy technologies office award # DE-EE0008752.
SUMMARY: Strain engineering is a powerful technique for controlling the band structure and properties of various two-dimensional (2D) materials. Black phosphorus (BP), a layered structured material in which each atomic layer of the puckered honeycomb lattices are stacked by van der Waals interactions, is an interesting candidate for strain engineering. That is because of its ability to sustain a high strain and because of effective strain-induced tuning of its mechanical, electronic, and optical properties. In order to better understand the strain effects in black phosphorous (BP), Drs Jasinski and Sumanasekera, together with their colleagues, conducted a comparative in-situ Raman study of strain-dependent vibrational modes in BP and samples of 2 phases of MoTe$_2$ crystals, namely 1T’- MoTe$_2$ and 2H-MoTe$_2$. The study showed that the strain-induced Raman peak shifting of BP is much stronger, by almost an order of magnitude, than that of both phases of MoTe$_2$, which can be understood as due to the lower Young’s modulus of BP. In addition, a remarkable resemblance between donor-type intercalation-induced vibrational properties (as found in their previous work: J. Phys. Chem. C 2020, 124, 19, 10710–10718) and tensile stress-induced vibrational properties in BP was also observed. This is because both mechanisms result in bond length increase in BP; the strain-induced Raman shifts of B$_{2g}$ and A$_{2g}$ modes against the shift of the A$_1^g$ mode follow the same linear dependence as due to Li$^+$ intercalation. The study suggests that the in-situ Raman spectroscopy can be an effective tool that can allow observation of strain effect directly which is critical for future flexible electronic devices.

This research used the core facilities at the University of Louisville Conn Center and was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, under award # DE-SC0019348; Publication: B. Karki, B. Freelon, M. Rajapakse, R. Musa, S.S. Riyadh, B. Morris, U. Abu, M. Yu, G. Sumanasekera, J. B. Jasinski. Strain-induced vibrational properties of few layer black phosphorus and MoTe$_2$ via Raman spectroscopy. Nanotechnology, 31(42), 425707 (2020).
SUMMARY: In recent years, van der Waals layered materials, have attracted significant attention as promising structures for a variety of applications, including thermoelectrics, e.g., materials for efficient conversion of heat to electricity. Owing to its unique properties, including high carrier mobility (1000 cm²(Vs)^−1 at room temperature (RT)), a tunable thickness-dependent bandgap (0.3–2.0 eV), a large Seebeck coefficient (335 μV K⁻¹ at RT), and a strong in-plane anisotropy, black phosphorus (BP) and its two-dimensional (2D) form, phosphorene, are among some of the most prospective thermoelectric materials. Recent investigations have indicated that the thermoelectric properties of BP can be further enhanced by alloying. Motivated by these reports, Drs. Jasinski and Sumanasekera along with two Physics graduate students (Bhupendra Karki and Manthila Rajapakse), successfully synthesized a series of AsₓP₁₋ₓ (0<x<0.83) alloys and conducted a comparative study of their structural and thermoelectric properties. The study shows that at low As concentration, these materials have very high thermopower values reaching 803 μV/K for As₀.₂P₀.₈, which is much higher than 323 μV/K of non-alloyed BP. Furthermore, the research indicated that the thermoelectric properties of BP can be greatly improved by alloying, resulting in comparable or even better performance than that of the reported outstanding thermoelectric materials.
SUMMARY: A recent progress in two-dimensional (2D) materials has led to the renewed interest in intercalation (i.e., a reversible process of inserting foreign ions or molecules in-between weakly-bonded layers), as a powerful tool when it comes to enhancing or tuning various materials properties or converting the existing layered materials into new structures and phases. Understanding intercalation in various layered systems is therefore of utmost importance. Here, in their research, Drs Jasinski and Sumanasekera, together with Dr. Yu from the Physics Department and a group of students, conducted a systematic study of electrochemical Li intercalation of black phosphorous (BP), using in-situ Raman spectroscopy as a primary probe of this process. Several other materials characterization techniques, including x-ray diffraction and electron microscopy, were also used to gain an in-depth understanding of the structural evolution that takes place during Li intercalation. The study shows that all three fundamental vibrational modes of BP, namely, $A_{1g}$, $B_{2g}$ and $A_{2g}$ red-shifts systematically during lithiation, while at the same time the crystal structure of BP undergoes a systematic volume expansion. The intercalation of BP is found to be a highly anisotropic process, as the Li diffusion takes place along structural channels which run in the so-called zigzag direction. Interestingly, in highly intercalated samples, Li diffusion along these channels causes the formation a network of weakly connected straps of few-layer BP. The study suggests, that such material can be used as a precursor for fabrication of phosphorene nanoribbons.

This research used the core facilities at the University of Louisville Conn Center and was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, under award # DE-SC0019348; Publication: M. Rajapakse, R. Musa, U.O. Abu, B. Karki, M. Yu, G. Sumanasekera, J.B. Jasinski, Electrochemical Li Intercalation in Black Phosphorus: In Situ and Ex Situ Studies. The Journal of Physical Chemistry C, 124(19), 10710-10718 (2020).
SUMMARY: We use theoretical methodology to guide the experimental effort to utilize defected perovskites as a tool for rational design of highly active electrocatalysts for water-splitting. Importantly, the newly proposed catalyst is based on earth-abundant metals. This exciting structure-activity relationship has been demonstrated through a systematic order-disorder transformation, controlled by the average ionic radius in three materials with formula LaA₂Fe₃O₈ (A=Ca,Sr). Experimentally, the structural order has been shown to result in a major enhancement of the electrocatalytic performance. In particular, the ordered material is found to be capable of catalyzing the hydrogen evolution reaction (HER) in both acidic and basic media. The theoretical calculations using density functional theory (DFT) indicate a major transformation of the electronic structure between ordered and disordered systems and shed light on the active sites in electrocatalytic processes.

DFT calculated band structure and PDOS for (top) LaCa₂Fe₃O₈ and (bottom) LaSr₂Fe₃O₈. The energy of the Fermi-level is set to zero. In band structures, red and blue lines denote contributions from spin-up and spin-down electrons, respectively.
SUMMARY: The Spurgeon group within the Solar Fuels Theme of the Conn Center is developing microparticles for unassisted solar-driven hydrogen generation from water. Technoeconomics suggest the particle slurry design can be among the most cost-effective approaches by eliminating many of the components of photovoltaics and electrolyzers within a simple integrated system, but semiconductor particle systems have typically suffered from low efficiency. The Conn Center work aims to improve this by using a two-semiconductor TiO₂/Si tandem microwire to more efficiently utilize the visible spectrum to generate the more than 1.6 V of photovoltage needed to split water. An innovative strategy to magnetically align the wires using the nickel hydrogen evolution catalyst has been developed to orient the wires and ensure proper sequential light absorption to the two bandgaps of the tandem for maximum efficiency.

Dr. Joshua Spurgeon, Conn Center for Renewable Energy Research, University of Louisville

This research used the core facilities at the University of Louisville Conn Center and the MicroNanoTechnology Center and was supported by an NSF CAREER Award # NSF 1943977.
Computer Science and Engineering
Founded in 1971, the CSE Department offers BS and MENG programs in CSE, an MS Degree (traditional and online) in Computer Science, and a Ph.D. Degree in CSE. The CSE faculty conduct research in machine learning, AI, data science, cybersecurity, computing systems, and bioinformatics, with recent annual research expenditures exceeding $2M.

**Vision for Research** I envision that machine learning, AI, and data analytics techniques will be increasingly used to solve computational, cybersecurity, interdisciplinary, industrial, healthcare, and social problems. Hiring junior and/or senior faculty in those top areas can strengthen our research and attract more funding and graduate students.

**Top Areas of Research**

- AI and Machine Learning
- Data Science
- Cybersecurity
- Computing and Networking Systems
- Bioinformatics and Interdisciplinary Computing Research
Optimizing Operating System Kernels for Low Latency Data Access

Dr. Nihat Altiparmak, Computer Science & Engineering

**SUMMARY:** With the ever increasing volume, variety, and velocity of data in our modern society, one dominant limitation to harnessing the data revolution at scale is the ability to access, move, and process data efficiently. Dr. Altiparmak’s [Computer Systems Laboratory](#) addresses current bottlenecks in low latency data access by optimizing operating system kernels for performance and energy efficient storage device interactions. Specifically, this research develops new data input/output submission, scheduling, and completion algorithms for the Linux kernel considering the characteristics of new generation Non-Volatile Memory devices. As today's most critical applications, including genome analysis, climate simulations, drug discovery, and space observation are all data intensive in nature, this research can have a considerable impact on society by accelerating the innovation process in a multitude of domains of science in an energy efficient manner.

National Research Priority: NSF 10 Big Ideas on Harnessing the Data Revolution

This research was supported by the U.S. National Science Foundation (NSF) under grants CNS-1657296, CNS-1828521, and OIA-1849213. Publication: Bryan Harris and Nihat Altiparmak. Ultra-Low Latency SSDs’ Impact on Overall Energy Efficiency. In 12th USENIX HotStorage ’20, July 2020.
SUMMARY: Several aspects of Artificial Intelligence, Machine Learning and Deep Learning have been the focus of research including publications and keynote presentations. Translating research results into actions and the value of storytelling to engage the user and management will has been an important part of the experience. Recent research applications utilized Deep Learning and range from medical imaging, Health related data, social network analysis, and natural language processing.

Cybersecurity **Triple-Crown Winner** in 2020 with over **$7.25 M** in 2020 funding from the top Three Federal Security agencies (DoD, NSA, and DHS) as PI, Co-PI and Co-Investigator.

Continued **Industry Partnership** in Healthcare Innovation with Kindred Collaboration in Hive. Explore Innovative partnership with multiple Industries to utilize AI and Intelligent Systems.

National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier
Dr. Adrian P. Lauf, Computer Science & Engineering

**SUMMARY**: Detection of Unmanned Aerial Vehicles (drones) is a complex topic due to challenges in selecting optimal sensing data sources and methods, such as optical, audio, and RF. This work relies on steady-state and transient signal analysis that captures the data stream from the operator control unit to the aircraft. Using discrete and continuous wavelet transform analysis along with a wavelet scattering transform, we are able to extract features from the signal that can train a convolutional neural network, machine learning classifier, or SqueezeNet. By using the signature scattergrams, we are able to achieve a recognition accuracy of over 98% at a signal to noise ratio of 3 dB. We are able to retain this accuracy even in the presence of other devices present on the same frequency band, and are able to identify which aircraft manufacturer is in use by the operator.
SUMMARY: The SARS-CoV-2 virus responsible for causing COVID-19 first emerged out of Wuhan Province, China, in December, 2019. Since that point in time, over 374,000 individual SARS-CoV-2 genomes have been sequenced worldwide, and deposited into the international GISAID database. Using publicly available data, as well as a cohort of 29 patients from the Louisville area, we have identified a number of variants that are population-specific, as well as common variants that are found within the viral population of a single human host. Our analysis of viral loads with clinical outcomes suggest that surprisingly, a lower viral load is associated with a poorer clinical prognosis. We have also identified gene expression with significant correlation (either positive or negative) to viral load, as defined by ΔCt values from rtPCR. Many of these are interferon-related, suggesting the role that inflammation plays in the progression of disease. Analysis of the corresponding nasopharyngeal microbiome also suggests shifts in the natural flora associated with disease severity.

National Research Priority: American Public Health Security and Innovation

This research used the KY-INBRE Bioinformatics core at the University of Louisville and was supported by NIH grant P20GM103436.

Genetic Analysis of SARS-CoV-2 Variants and the Role of Viral Load in Severity


Dr. Eric Rouchka, Computer Science and Engineering

**SUMMARY:** Machine learning approaches can be used to analyze behavioral and functional data in order to identify clusters of differences and similarities for subjects/animals with spinal cord injury (SCI), in particular those exposed to a regimen of activity/exercise. These phenotypic responses can then be integrated with "-omics" data to identify biological processes, cell-types, and individual genes that are associated with distinct behavioral-based outcomes, acutely and chronically.

In this project, we are collecting, organizing, and integrating behavioral, functional, and transcriptional data both from our own studies as well as publicly available datasets in a manner that is Findable, Accessible, Interoperable, and Reusable (FAIR), as well as developing machine learning approaches to pull out additional information from these data sets. We are also developing an iterative approach for integrating transcriptomic and behavioral data using Topological Data Analysis. The final aim will produce additional behavioral and transcriptomic data for SCI models incorporating A/E.

**National Research Priority: Understanding the Rules of Life**

This research used the KY-INBRE Bioinformatics core at the University of Louisville and was supported by NIH grant P20GM103436 and a grant from the Wings for Life Foundation.
**Dr. Eric Rouchka, Computer Science and Engineering**

**SUMMARY:** The length of untranslated regions at the 3’ end of transcripts (3’UTRs) is regulated by alternate polyadenylation (APA). 3’UTRs contain regions that harbor binding motifs for regulatory molecules. However, the mechanisms that coordinate the 3’UTR length of specific groups of transcripts are not well understood. We therefore developed a method, CSI-UTR, that models 3’UTR structure as tandem segments between functional alternative-polyadenylation sites (termed cleavage site intervals – CSIs). This approach facilitated 1) profiling of 3’UTR isoform expression changes and 2) statistical enrichment of putative regulatory motifs. CSI-UTR analysis is UTR-annotation independent and can interrogate legacy data generated from standard RNA-Seq libraries.

**National Research Priority: Understanding the Rules of Life**

This research used the KY-INBRE Bioinformatics core at the University of Louisville and was supported by NIH grant P20GM103436.

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Artificial Intelligence: Control, Explainability and Predictability

Dr. Roman Yampolskiy, Computer Science and Engineering

**SUMMARY**: Invention of Artificial General Intelligence (AGI) is predicted to cause a shift in the trajectory of human civilization. In order to reap the benefits and avoid pitfalls of such powerful technology it is important to be able to control it. However, possibility of controlling artificial general intelligence and its more advanced version, superintelligence, has not been formally established. Dr. Yampolskiy’s research is aimed at establishing limits to what is possible in terms of control, explainability, comprehensibility and predictability of intelligent systems. Understanding such limits of AI is important for intelligent systems deployed in real-world domains. Users want and frequently need to understand how decisions impacting them are made. Similarly, it is important to understand how an intelligent system functions for safety and security reasons. Yampolskiy’s research on AI Safety and Security spans all levels of capabilities from narrow AIs of today to superintelligent machines of tomorrow.

Dr. Roman V. Yampolskiy, Computer Science and Engineering, University of Louisville
2020 papers in: Patterns 1(2), JAIC 7(2), 7(1), Philosophies 5(4), Physica Scripta 95(6), JAGI 11(2), AGI, others.

Right - Control and autonomy curves as capabilities of the system increase
A Suggestive Interface for Untangling Mathematical Knots

Dr. Hui Zhang, Computer and Science Engineering

SUMMARY: In topology, knot theory is the study of mathematical knots. In this research we investigate a user-friendly sketching-based suggestive interface for untangling mathematical knots with complicated structures. Rather than treating mathematical knots as if they were 3D ropes, our interface is designed to assist the user to interact with knots with the right sequence of mathematically legal moves. Our knot interface allows one to sketch and untangle knots by proposing the Reidemeister moves, and can guide the user to untangle mathematical knots to the fewest possible number of crossings by suggesting the moves needed. The system highlights parts of the knot where the Reidemeister moves are applicable, suggests the possible moves, and constrains the user's drawing to legal moves only. This ongoing suggestion is based on a Reidemeister move analyzer, that reads the evolving knot in its Gauss code and predicts the needed Reidemeister moves towards the fewest possible number of crossings. In addition, understanding of a fairly long mathematical deformation sequence in our interface can be aided by visual analysis and comparison over the identified "key moments" where only critical changes occur in the sequence. All these combine to allow a much cleaner exploratory interface for us to analyze and study mathematical knots and their dynamics in topological space.

Dr. Hui Zhang, University of Louisville. This research was funded by NSF #181581.

Publications:
- Zhang, H.; Liu, H., “Relaxing topological Surfaces in Four Dimensions” The Visual Computer 36(10), 2341-2353. 2020
Dr. Wei Zhang, Computer Science and Engineering

**SUMMARY:** GPUs have recently become popular to host the encryption/decryption algorithms due to its high-throughput parallel computing capability to accelerate computation. However, the security issues of moving the cryptographic algorithms onto GPUs have not been studied adequately. Consequently, with absence of any protection strategy, the potential vulnerabilities of GPUs to side-channel attacks may expose the confidential information with high risk. Dr. Zhang and his team are exploring the timing behavior of GPU computing and its correlation with hardware security. Their recent work studied a Profiling-Assisted Correlation-based Side-Channel Attack (pacSCA) to demonstrate that ignoring security issues and naively moving security services onto GPUs can offer adversaries fatal vulnerabilities to thieve critical information. The results show that the proposed SCA can rebuild the secure key of the AES-128 algorithm running on a GPU in less than 6 seconds, revealing the urgency of developing SCA-aware countermeasures for protecting GPUs against timing-based side-channel threats.

This research was recently published and presented at the 38th IEEE International Conference on Computer Design (ICCD) in October 2020. This work was funded in part by the NSF grants CNS-1421577 and SaTC-1623277.
Electrical and Computer Engineering
The Electrical and Computer Engineering (ECE) Department offers 4 degrees: BSEE, M.Eng., MSEE and PhD. Our department has about 300 students, broken down into 225 undergraduates and 75 graduates. Also, our department has 14 full-time faculty and brings in about $3M per year in research or about 30% of the SSoE total. ECE oversees 4 research centers within SSoE: CVIP, ERINC, LARRI & MNTC.

**Vision for Research** Our goal as a department is continue to grow our research funding and remain the top research department within SSoE. We will accomplish this through strategic hires of top researchers having well established research records to continue to grow and support our research centers. We will also be working hard to establish relationships with industry to help drive funding of our research centers and the new Speed Research Park.

**Top Areas of Research**
- MEMS and Microelectronics
- Robotics
- Imaging
- Machine Learning and AI
- Communications, Controls and Optics
SUMMARY:

Radiomics is an emerging field that converts imaging data into a high dimensional feature space using image processing algorithms to diagnose disease or predict outcome. Features are extracted for radiomics using either hand-crafted feature extraction algorithms or with Deep Learning-based feature extractors. The former of the two methods requires an image processing practitioner to build a mathematical technique that can be applied to the images that measures specified features of interest (e.g. nodule shape or texture). Deep Learning-based features extractors on the other hand which are becoming more prevalent in medical image informatics, are showing success in extracting features across a whole host of medical image classification (among a myriad of other tasks) without the need for meticulously designing mathematical techniques.

Deep learning entails use of a network of neurons with weighted connections in several layers that abstract out information content in images producing highly compact feature sets that may be used in image classification, image labeling, and image synthesis, among others. The network learns the connection weights through optimization procedures before being presented new data for testing. Our laboratory is highly active in this research space – please see references for recent publications in this area.


**SUMMARY:** MRI is noninvasive and as with ultrasound, has the capability to image the anatomy as well as velocity and flow. Compared to ultrasound however, the velocities can be measured in all 3D directions and do not require any geometric assumptions. Furthermore, with the advent of 4D flow imaging, MRI permits 3D visualization of flow, particle traces, and flow path lines as part of a single scan. Despite advances, standard 4D flow imaging techniques suffer from long scan times and when imaging flow distal to severe narrowings such as stenotic valves have been hampered by artifacts. We have addressed these shortcomings through development of scan efficient 4D flow techniques adopting non-Cartesian k-space trajectories which significantly reduced echo times (TE) (1, 2) and flow artifacts. Recently, we developed a Dual Venc 4D Spiral Flow sequence (3), significantly improving velocity-to-noise ratio and quality of the diastolic flow images.


Self-Assembly of Polymer Nanostructures

Prof. Robert W. Cohn, Electrical and Computer Engineering

SUMMARY: The nanostructure is project is developing high production rate methods of fabricating soft, suspended polymer nanostructures by processes that can be used in production wafer steppers and roll-to-roll manufacturing system. The ability to affordably add suspended nanostructures above the traditional electronic layer of integrated circuits would enable greatly increased device and system-in-a-package functionality, with significant impact on capabilities and pervasiveness of the Internet of Things (IoT). As shown in the figure, the method is based on photopatterning suspended films of sub-100 nm thick polymer films, followed by thermal anneal. Current extensions to the method shown in the figure, are ways to pattern multilayers of these films in ways that self-assemble three dimensional nanostructures, including the nanopillar supports shown in the illustration.

National Research Priority: Advanced Manufacturing and Semiconductors.

Figure 1. 2D STP. Method and example of transform of holes in an 80 nm thick polystyrene film into a latticework of fibers. The film is processed on top of an array of square micropillars.

Shape Transformation Photolithography (STP)

This research used the core facilities at the University of Louisville ElectroOptics Research Institute and Nanotechnology Center and was supported by NSF Award # ECCS 0506941. Publication: A. Sherehy, J. M. Rathfon, H. Abe, S. S. Chowdhury and R. W. Cohn, “Shape transformation photolithography: Self-assembled arrays of suspended MEMS structures from patterned polymer membranes,” ACS Omega 3, 18489-18498 (2018)
SUMMARY: The fundamental research question to be addressed relates to improving student learning by the automated capture of non-verbal cues of engagement: How can we use students' expressions of engagement, based on non-verbal signs such as facial expressions, body and eye movements, physiological reactions, posture, to enhance learning? Project Goals are:

1. Establishment of a robust network of non-obtrusive and non-invasive sensors in mid-size classes to enable real-time extraction of facial and vital signs, which will be integrated and displayed on instructors' dashboards;
2. Identification of robust descriptors for modeling the emotional and behavioral components of engagement using data collected by the sensor networks;
3. Conduct a pilot testing of the system's effectiveness in gathering meaningful data for subsequent work on emotional, behavioral, and cognitive metrics of engagement.

Student’s engagement measurement relies on i) eye-gaze; ii) head movement; iii) hand movement, and facial expressions. Videos captured by webcams are used to extract facial; information and eye-gaze. Video captured by wall-cam is used to hand and body movement. 3D reconstruction shows the students’ heads and gazes relative to the target teacher board.

This research used the core facilities at the University of Louisville Computer Vision and Image Laboratory and was supported by NSF Award #1900456. Publication: J. C. Foreman, A. Farag, A. Ali, I. Alkabbany, M. S. DeCaro and T. Tretter, "Towards a multi-dimensional biometric approach to real-time measurement of student engagement in the STEM classroom," in Proceedings of the American Society for Engineering Education, 2020.
SUMMARY: Colorectal cancer (CRC) originates as small growths (polyps) attached to the luminal wall of the colon and rectum. If polyps are not diagnosed and treated, they may grow and become cancerous. There are four common methods to screen for CRC: 1) Fecal occult blood test (FOBT), which detects blood in a stool sample that is not visible; 2) A fecal immunochemical test (FIT), which detects occult blood in stool; 3) Optical Colonoscopy (OC), where a flexible endoscope is inserted to visually inspect the interior walls of the rectum and colon; and 4) Computed Tomography Colonography (CTC), a CT-based technology for visualizing the interior of the colon. Our hypothesis is that a proper synchronization of CTC and OC holds the best route for combating CRC. At the CVIP, we developed state of the art methodologies to visualize the colon, starting from abdominal CT of prepped patients, detect the polyps and track their growth. Our efforts are coordinated with a comprehensive team of clinicians and is pursued for commercialization by Kentucky Imaging Technologies (KIT).

This research used the core facilities at the University of Louisville Computer Vision and Image Processing Lab was supported by NSF Award # NSF 1602333 SCH: EXP: A Quantitative Platform for CT Colonography. Publication: M Mohamed, A. Ali, S Elshazly, A Farag: "Stabilizing visualization by reducing camera movements in virtual colonoscopy methods" Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization; November 2020. https://doi.org/10.1080/21681163.2020.1835557
Frame Stitching in Human Oral Cavity Environment Using Intraoral Camera

Dr Aly Farag, Electrical and Computer Engineering

**SUMMARY:** Intra-oral cameras enables dentists to capture images of difficult-to-reach areas in the mouth. The information content in these images is rich and can be used for creating a 3D model of the human jaw, which would benefit various dental practices. However, oral dental applications based on visual data pose various challenges such as low lighting conditions and saliva. The mouth is a challenging imaging environment, due to lighting conditions, decay, missing teeth and saliva, which complicates the process of feature extraction for reconstruction. At the CVIP Lab, we created an approach to stitch images of human teeth that are captured by an intra-oral camera. We designed a novel algorithm to handle a lack of features region correspondence in the mouth. We estimate normal maps of captured images using SFS. These normal maps have plenty of features. Also, they are used to estimate as-projective-as possible warps, which enhance the stitching process. Overall, this work is a part of long-term efforts to create an optical-scanning mechanism for various dental procedures.

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This research has been supported by Kentucky Imaging Technologies, for data, hardware support and dental expertise.

Sample Publications:

Dr. Cindy Harnett, Electrical and Computer Engineering

**SUMMARY**: Soft and stretchable optical fibers are a promising all-polymer sensor element for extreme mechanical strains, pressures, bending and other deformations. Compared to electronic sensors, the sensor elements are intrinsically stretchable and are not subject to electromagnetic interference. However, the typical approach of measuring deformation by tracking the transmitted light intensity is an integrating approach similar to resistance-based measurements; it does not provide information about the location or the nature of the deformation. We investigate an alternative sensing method with our lab-produced stretchable optical waveguides: measuring their lengths via the time of flight (TOF) of a light pulse. This approach is a miniaturized, optics-based version of previous acoustic TOF and electronic time-domain reflectometry in robotics and human-interface devices. Such ranging systems collect spatial information using a small number of sensors. The TOF approach can measure fiber lengths to within 1 mm on an overall length of ~330 mm (>1% accuracy).

Personalizing Drug Delivery through Clinically Relevant Modeling and Control

Dr. Tamer Inanc, Electrical and Computer Engineering

SUMMARY: Tools that are used to determine the dose of a drug to deliver to a patient range from specific instructions contained in the drug package insert to tools used by pharmacists for the dosing of aminoglycoside antibiotics. In the case of the latter, physicians have been fairly accurate since there are sufficient information about the pharmacokinetics of the aminoglycosides and, combined with peak and trough drug levels, useful dose recommendations can be provided. In the case of the former, often physicians are left to a form of trial-and-error dosing in which adjustments are made to the dose as the results are observed for each specific patient. The current system works for the drugs which have a wide therapeutic window or mild toxicity. However, when faced with a drug that has a narrow therapeutic window, high toxicities, large inter-patient variability or significant dosing restrictions, it becomes difficult for the practitioner to determine what dose of the drug to give. Often these agents are only given successfully by a few specialized individuals with the clinical expertise to manage these patients. This process is inherently imprecise and advances in engineering and computational intelligence may help to alleviate much of the uncertainty when dosing these agents.

This research aims to investigate a new methodology for the development of individualized patient models and a novel control approach for personalized drug dosing. In the short term, this effort will impact the treatment of anemia, a common chronic condition in hemodialysis patients. The successful completion of the proposed research, however, has the potential to result in a new method for personalized drug dosing that can be applicable to many other chronically administered drugs that require some type of monitoring.

National Research Priority: NSF 10 Big Ideas on Smart and Connected Health.

NSF Project with Drs. Jacek M. Zurada, Michael M. Brier, Adam E. Gaweda and Alfred A. Jacobs.

Figure. Achieved Hb levels (top) and EPO dose adjustments (bottom) in presence of Hb error obtained from MRHC, SAM, and AMP for average and poor responders.

This research is supported by the National Science Foundation (NSF) under Award Number 1722825.

The increasing demand for wireless communications, the reduction of spectrum availability due to auctioning, and the emergence of new vehicles in the airspace (such as Urban Air Mobility (UAM), Unmanned Aircraft Systems Traffic Management (UTM), and supersonic aircraft) will result in an increased mission diversity and airspace density that will saturate the availability of existing aviation spectrum channels. Consequently, there is a pressing need to develop a new approach for spectrum management that employs modern technologies in communication and networking, artificial intelligence (AI), cloud/edge computing and others to maximize the utilization efficiency of spectrum available for aviation use. The study objective is to ensure that the rapidly growing number of aircraft will have full access to the increasingly crowded aeronautical spectrum through intelligent and autonomous spectrum allocation.

Communications in Future Airspace

This research is supported by NASA and National Institute of Airspace
**SUMMARY:** The control of electric machinery has been an ongoing challenge from control systems engineers for many years. Electric machines (rotational/translational) utilize electric energy to create mechanical power through speed and torque/force. These systems often drive mechanical apparatus that are highly nonlinear and uncertain. For these systems, the user desires to control the mechanical states regardless of this nonlinear behavior over a wide range of operating conditions. Our research focuses on the control of novel machines types in addition to driving nonlinear and uncertain loads. Our work also includes the power electronic systems which adds a level of complexity and difficult when developing these solutions. Our group has experience with the control of induction, synchronous, brushless DC and linear machines to name a few specific types. Our group has developed numerous observers for these machine types that are used in sensor-less control and fault detection applications. As energy efficiency demands increase our future work will develop robust control solutions for traction drives for electric vehicles.

National Research Priority: Smart/Adaptive/Learning Systems; Energy Efficiency Application, Transportation Electrification

This research used the Electrical Energy Systems research lab in WS Speed 209, and 217.

- This research has been supported by 11 research contracts with GE Appliances.
- This work has resulted in 8 US Patents.
- My students and I have published 3 journal and 3 conference publications in this area, to date.
SUMMARY: Modern Wind Energy Conversion Systems (WECS) utilize rotating generators to harness the energy of wind and convert it to electricity. However, turbulent wind profiles can make it difficult to extract a maximal amount of energy. Dr. Nick Hawkins, alongside Dr. Michael McIntyre’s research group, address this issue by using nonlinear control methods to more quickly and precisely control the rotation of these generator for optimal performance. Generator rotation can be controlled in this way by managing the voltage and current at the electrical terminals of the machine. For example, as compared to a more typical control scheme, they have shown this strategy can be up to 250 times more accurate when following a desired rotational speed trajectory. This work improves the efficiency of variable-speed WECS and decreases turbine wear from turbulent wind conditions.

National Research Priority: US Department of Energy Wind Vision

At the right is a diagram of a variable-speed WECS, which uses a multi-stage power converter to transition from AC to DC and back to AC power (from left to right).

At the left are the average errors while controlling a Squirrel Cage Induction Generator (SCIG) through turbulent wind with a typical scheme (top) and a nonlinear scheme (bottom). In this case, a smaller error translates to higher accuracy.

Publications:
**SUMMARY:** Professor McNamara’s research has three focus areas. (1) Microfabricated sensors. A variety of sensors have been designed, fabricated, and measured, including accelerometers, pressure sensors, and resonators. One highlight are extremely low power sensors using only a few nanoWatts of power. (2) Nanofluidics. One major project is the development of Knudsen gas pumps. These are pumps that are thermally driven and have no moving parts. A second major project is the development of a Tactile Tablet for blind persons. We are developing a device that can provide graphical information to blind persons. (3) Microelectronics. Professor McNamara’s lab is developing ultra-low power electronic devices based on quantum tunneling, developing novel low power memory for computers, and working on wide-bandgap semiconductors for high-power applications.

(top left) Multifunctional nano-porous thermoelectric that is also used for a thermally driven Knudsen gas pump. (top middle) GaN MEMS Resonator. (top right) Electrostatically actuated valves that unroll (bottom left) CMOS Circuit fabricated in the UofL cleanroom. (bottom middle) Low power resonator based on tunneling current. (bottom right) Piezoresistive resonator.

This research used the UofL MicroNanoTechnology Center core facility and has been supported by NSF and the Department of Defense.
SUMMARY: Wearable sensing and telemedicine devices are increasingly considered valuable in health monitoring and the detection of illness. Three recent examples developed in Dr. Naber’s lab are shown to the right. The wireless incontinence monitor with body temperature and movement detection addresses root cause conditions that leads to UTIs and pressure injuries in assisted living facilities. Successful field tests have been completed and the device is being commercialized. The newest device under development is a wrist wearable that can measure SpO2, Heart Rate and Temperature with a battery life of 1 month. The tocodynamometer device measures labor contractions for the detection of Braxton Hicks “false labor”. The device has been clinically tested and is also being commercialized. The Doppler ultrasound fetal heart rate monitor is designed to monitor heart rates during late term pregnancy. Preliminary tests were successful and work to refine this product continues. Dr. Naber’s lab also supports research by providing design and fabrication of supporting electronic devices. Examples show a computer controlled source for low resistance loads, a four channel motor controller, and a regulated 405nm light exposure test device used for the study of killing bacteria.

This research used the facilities in the Shumaker Research Building. Support is provided by industry contracts and by support for other research groups.
Dr. Dan Popa, Electrical and Computer Engineering

Summary: In this work we are building a new type of additive manufacturing instrument that incorporates industrial robots and custom high precision robots, along with a variety of processes such as 3D Printing, Ultrasonic Bonding, Aerosol Jetting, Microassembly, Electronic Pick and Place, Intense Pulse Light Curing and Fiber-Weaving. When completed, the NeXus will be able to custom manufacture sensor and MEMS prototypes such as pressure-sensitive robotic skins, electronic textiles, solar cells, and microrobots. The system will be equipped with advanced human-machine interfaces to control and coordinate the additive manufacturing processes and will provide the UofL’s NNCI node added prototyping research capabilities beyond the cleanroom.
Dr. Chuang Qu, Electrical Engineering

**SUMMARY**: This research demonstrates the first use of an advanced physical vapor deposition technique – GLancing Angle Deposition (GLAD) – to fabricate nanoporous membranes for applications as a MEMS-based Knudsen gas pump. GLAD is capable of creating nanometer-level three-dimensional (3D) features by ballistic shadowing from natural/artificial nuclei at oblique incident angles. GLAD process offers enhanced tunability of the size, shape, and density of nano-features. The GLAD features with sub-100 nm features sizes, including columns, springs, and zigzags, are building blocks of a wide range of optical, mechanical and sensing applications. In addition, the GLAD nanostructures can be templates for creating nanoporous membranes, which are used in Knudsen pumps. The Knudsen pump reported here has the same pressure as reported in using a membrane thickness of only 10 μm. This bottom-up process provides higher throughput, simplified manufacturing process and significantly reduced fabrication cost.

**National Research Priority: Growing Convergence Research**

This research was performed in part at the KY Multiscale, a member of the National Nanotechnology Coordinated Infrastructure (NNCI), which is supported by the National Science Foundation (ECCS-Grant No. 2025075).

Publication:
Dr. Chuang Qu, Electrical Engineering

**SUMMARY:** This work focuses on a bottom-up fabrication process entitled Glancing Angle Deposition (GLAD). GLAD is suitable for the fabrication of three-dimensional nanostructures, which is challenging from conventional top-down nanomanufacturing techniques. Various nanostructures with feature size below 100 nm, such as columns, chevrons, springs, and ribbons by line seeds, are fabricated by GLAD. This research focuses on the GLAD process with line seeds by integrating the design, fabrication and optimization of line seeds for obtaining nanoribbons. The thickness of the GLAD ribbons is controllable by the geometric parameters of the seeds; sub-100 nm-thick ribbons are obtained from micrometer-width lines created using conventional photolithography. The fabrication of centimeter-long nanoribbons and the use of the ribbons as templates for nanochannels are demonstrated. The nanoribbons can be used as strain sensors, as well as templates for nanoporous structures (such as nanochannels) which are potentially used in nanofluidics, medicine and biology applications.

National Research Priority: Growing Convergence Research

This research was performed in part at the KY Multiscale, a member of the National Nanotechnology Coordinated Infrastructure (NNCI), which is supported by the National Science Foundation (ECCS-Grant No. 2025075).

Publication:
Dr. Dilan Ratnayake, Electrical Engineering

**SUMMARY:** Many experts predict that the world will contain a trillion IoT devices by 2035. If that becomes the new reality, the energy needs for those sensors will need to be addressed. One solution is to design sensors with “smart” materials that harness the inherent internal mechanical energy of the devices themselves as they respond to the environment, thus completely eliminating the need for batteries. This new approach has opened up a new field of study which some refer to as “no-electrical-power (NEP) event-driven sensing”. This research contributes to that body of knowledge as we propose a new fundamental building block for NEP event-driven sensors. In this project, we report the first bistable structures formed by combining stress-free and stress-engineered thin films. Oxide is used as our stress-inducing layer and polyimide (PI) as our stress-free mechanical layer. For thermal actuation, aluminum is then added as the actuation layer.

**Publication:**
Dr. Kevin Walsh, Electrical Engineering

**SUMMARY:** Professor Walsh’s research is focused in 2 primary areas – 1) the development of novel microelectromechanical system (MEMS) devices with an emphasis on novel bistable, no electrical power (NEP), event-driven sensors, and 2) the integration of various advanced manufacturing technologies that span multiple length scales. With the Internet of Things (IoT) predicted to require over a trillion sensors in the near future, it is critical that new strategies be developed that facilitate battery-free sensing modalities. This can be accomplished by cleverly designing “smart materials” which both power the sensors and initiate the desired response. As an example, Dr. Walsh’s research group has pioneered the use of engineered stress in polyimide-oxide diaphragms to produce NEP MEMS-based sensors that respond to predetermined thresholds of pressure and temperature. Examples are shown in the figure to the right. Dr. Walsh’s second research thrust is in the integration of micro/nano fabrication strategies with the next-generation of meso/macro advanced manufacturing processes, such as 3D printing and aerosol jet printing. Examples are shown in the figure to the right which illustrate the integration of KOH micromachining with non-planar direct writing of silver conductive traces.

**National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier**

This research used the UofL MicroNanoTechnology Center core facility and was supported by NSF Award # 2025075.
Review on Measuring Affect with Practical Sensors to Monitor Driver Behavior

Dr. Karla Conn Welch, Electrical and Computer Engineering

**SUMMARY:** Using sensors to monitor signals produced by drivers is a way to help better understand how emotions contribute to unsafe driving habits. The need for intuitive machines that can interpret intentional and unintentional signals is imperative for our modern world. However, in complex human–machine work environments, many sensors will not work due to compatibility issues, noise, or practical constraints. This review focuses on practical sensors that have the potential to provide reliable monitoring and meaningful feedback to vehicle operators—such as drivers, train operators, pilots, astronauts—as well as being feasible for implementation and integration with existing work infrastructure. Such an affect-sensitive intelligent vehicle might sound an alarm if signals indicate the driver has become angry or stressed, take control of the vehicle if needed, and collaborate with other vehicles to build a stress map that improves roadway safety. Toward such vehicles, this paper provides a review of emerging sensor technologies for driver monitoring. In our research, we look at sensors used in affect detection. This insight is especially helpful for anyone challenged with accurately understanding affective information, like the autistic population. This paper also includes material on sensors and feedback for drivers from populations that may have special needs.

National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier

The affective circumplex with adaptation of an overlay of four colored ovals, representing which quadrants likely relate to safer or riskier driving behaviors. Adapted from Russell (1980). Representative studies to support the effect on driver behavior are covered in the publication (Welch, Harnett, & Lee, 2019).

**Summary:** Today's deep learning networks aka. Machine Learning (ML) algorithms lead to very complex models of data. While these models are widely accepted as the most accurate, they are the least transparent at the same time. Hence, to develop trust in ML algorithms, explainable deep neural networks are needed. This leads to architectures with reduced number of feature extractors and low non-redundancy. It also leads to smaller, or skeletonized, networks with more distinct encodings. Our architectures of interest include autoencoders, multilayer perceptrons and convolutional networks, while the methods to enforce transparency use network sparsification, regularization, clustering and elimination of redundant filters. Our recent focus has been on developing networks with non-negative weights.

Our work aims at evaluating how data can be better modeled, explored and understood. The following relevant integrative problems are at the intersection of ML and bioengineered systems: (1) How to represent experimental visual data with non-negative encodings only, (2) How to inform the complexity of layers, i.e., the size of feature maps and receptive filters (more simpler filters vs. fewer complex filters), (3) How to guide the choice of the number of layers, also in the context of hyper-parameter tuning, (4) How (and if) to apply pooling for non-negative processing, (5) What are the connections between this paradigm of deep learning and related biological evidence in context of the selected architectures.

**NSF Project, with Dr. Tamer Inanc, Co-PI: Additive Parts-based Data Representation with Nonnegative Sparse Autoencoders**

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**Fig. 2.** Filtering the signal through the $L_1/L_2$-NCSAE trained using the reduced MNIST data set with class labels 1, 2, and 6. The test image is a 28 x 28 pixels image unravelled into a vector of 784 values. Both the input test sample and the receptive fields of the first autoencoding layer are presented as images. The weights of the output layer are plotted as a diagram with one row for each output neuron and one column for every hidden neuron in ($L - 1$)th layer. The architecture is 784-10-10-3. The range of weights is scaled to $[-1, 1]$ and mapped to the gray color map. $\alpha = -1$ is assigned to black, $\alpha = 0$ to gray, and $\alpha = 1$ is assigned to white color. That is, black pixels indicate negative, gray pixels indicate zero-valued weights, and white pixels indicate positive weights.

Ayinde, B.O., Inanc, T., and Zurada, J.M., "Redundant Feature Pruning for Accelerated Inference in Deep Neural Networks", Neural Networks, 118, pp.148-158, 2019

Ayinde, B. O., Inanc, T., and Zurada, J.M. "Regularizing deep neural networks by enhancing diversity in feature extraction." IEEE Transactions on Neural Networks and Learning Systems, vol. 30, No. 9, pp. 2650-2661, 2019
Engineering Fundamentals
Engineering Fundamentals

Dr. Ralston, Chair

The Department of Engineering Fundamentals (EF) was established in 2007 specifically to engage and support students as they begin their pursuit of an engineering degree. Department Faculty are focused on engineering and STEM education research and the scholarship of teaching and learning, some exclusively, others in tandem with their disciplinary research.

Vision for Research Engineering Fundamentals research is focused on translating recent work of psychologists and cognitive scientists to the undergraduate engineering classroom, as well as strengthening high school science teachers’ skills in teaching engineering topics. Many of our research active faculty work with educational psychologists and teacher educators from the College of Education and Human Development and cognitive scientists from the Department of Psychological and Brain Sciences.

Top Areas of Research

• Spacing and Exploratory Learning in STEM undergraduate courses
• Understanding freshmen engineering students’ interest in engineering and how it relates to first year retention
• Engineering education professional development for high school teachers
Exploratory learning is an active-learning technique that has been shown to improve students’ conceptual understanding and is therefore well suited for STEM education. Exploratory learning reverses the typical order of instruction, by having students explore a novel problem prior to instruction. The current project will test for the causal effectiveness of exploratory learning in multiple sections of four first- and second-year undergraduate STEM courses (biology, chemistry, physics, and engineering-mathematics), by comparing exploratory learning to traditional lecture-then-practice methods. STEM faculty, discipline-based education researchers, and a cognitive scientist are working together in a community of practice to develop exploration activities and assessments for each course. With over 3000 students slated to participate in two exploratory learning activities across four STEM disciplines, this project will substantially expand the number of controlled experiments testing the use of exploratory learning in undergraduate STEM courses.

Results from two pilot studies found students in the explore-first condition scored significantly higher than students in the instruct-first condition on the conceptual knowledge subscale of the posttest.

This work is funded by NSF Award # 2012342 and is a collaboration with Dr. Marci DeCaro (PI), Department of Psychology and Brain Sciences, Dr. Linda Fuselier, Department of Biology, and Dr. Raymond Chastain, Department of Physics.
Spaced Retrieval Practice in STEM Barrier Courses

Dr. Patricia Ralston, Engineering Fundamentals

**SUMMARY**: Spaced retrieval practice is an instructional technique in which multiple questions about the same topic are administered over time, with delays in-between. Derived from a cognitive science understanding of memory, spaced retrieval practice has been found to improve short- and long-term memory, but experiments have been primarily in the laboratory with language learning. In 2020, we implemented spaced retrieval practice in 10 STEM courses across the university, including Biology, Chemical Engineering, Chemistry, Engineering Mathematics, Physics, and Psychology, with the goal of improving student performance and helping students succeed. Through 5 workshops, we helped instructors create target learning objectives and retrieval practice questions for their courses, and then helped them to embed 6 ancillary cumulative quizzes in their courses. We collected data throughout the fall semester to assess the effectiveness of spaced retrieval practice. Results TBD.

National Research Priority: NSF 10 Big Ideas on Transforming Education to help Broaden Participation in Science and Engineering

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**Encoding, storage, and retrieval are the three primary stages of memory. Practicing retrieval strengthens memory, especially with time between each consecutive recall.**

This work was funded by NSF Award #1912253, and is in collaboration with Dr. Keith Lyle, Department of Psychological and Brain Sciences, Dr. Jason Immekus, Department of Educational Leadership, Evaluation & Organizational Development, and Dr. Campbell Bego, Engineering Fundamentals, University of Louisville. Collaborators are all members of the Guild for Engineering Achievement, Retention, and Success (GEARS) research group.
Dr. Brian Robinson, Engineering Fundamentals

**SUMMARY:** This project establishes a new RET site at SSoE and will foster a synergistic, triangular partnership between higher education, the Jefferson County Public School (JCPS) system, and energy-related industry in the Louisville, KY metro area. Select science teachers from JCPS will participate in a six-week summer experience working with UofL engineers on energy-related research and education. These teachers will utilize this experience to modify and augment existing science curriculum for the following academic school year and beyond. Energy represents a unifying theme across all scientific domains, and energy-related research included in this program will further SSoE research in this field. The high school teachers will strengthen their perspectives on engineering research, particularly with respect to variations in engineering design – a topic that is part of the high school science standards in Kentucky. The engineering faculty and participating SSoE students will benefit from a deeper understanding of the context and goals of high school science teaching – schools from which many of the entering engineering students have matriculated. In a context of energy-related environmental, political, and economical concerns of the modern world, experiences to support a stronger energy-literate culture are helpful for all. Subsequent improvements to high school student understandings of fundamental energy concepts and engineering design principles are expected to have a positive impact on student interest in STEM-related careers.

**Project objectives are summarized as follows:**

1) **Enhance the understanding of energy-related science and engineering, for 30 different high school science teachers from Jefferson County Public Schools (JCPS), via direct, authentic research experiences.**

2) **Strengthen high school science teachers’ pedagogical understandings of engineering design principles and the NGSS, so that developed, energy-related curricular elements and/or established learning outcomes from subsequent academic school year(s) are NGSS-aligned.**

3) **Guide and support high school science teachers as they translate their summer engineering research experience(s) into the academic school year.**

4) **Augment high school student understanding of fundamental energy concepts and principles, in addition to their interest in STEM-related careers.**

5) **Initiate and develop a synergistic, triangular relationship between JCPS personnel, faculty from the Engineering and Education departments at UofL, and energy-related industry partners from the community.**

6) **Establish and implement effective means of disseminating key RET project deliverables – especially curricular modules – that can influence many more high school science teachers and students within the region as well as nationally.**

This research is supported by NSF Award # NSF IIP 1855237, and will utilize several core facilities at the University of Louisville, including the Conn Center, Phoenix House, Passive Solar Test Facility (PSTF), Engineering Garage (EG), Science & Innovation Garage for Material Advancement (SIGMA), and the Geomechanics Laboratory.
**SUMMARY:** Falls are a common cause of injury in children but are also commonly provided as a false history in cases of child abuse. Distinction between accidental and abusive injuries in children often depends on an assessment of whether a child’s injuries are compatible with the stated injury cause. Biomechanics and computer models can provide objective information regarding injury potential in specific fall scenarios to aid in this assessment and to improve accuracy in child abuse diagnoses. In this study, a finite-element model of an 11-month-old child’s femur was developed and used in virtual simulations of common pediatric fall scenarios. The femur model was developed using a CT scan of a child’s femur and published material properties for pediatric bone tissue. Loading derived from experimental simulations of falls using an instrumented child surrogate was applied to the model. Peak stress and strain in the femur were evaluated for assessment of fracture risk.

This research was supported by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the NIH, Award number R03HD078491.

Industrial Engineering
Dr. Pratik J. Parikh, Chair

The Department of Industrial Engineering (IE) was established in 1977. We take pride in the fact that we are the only IE department in the Commonwealth of KY. IEs are engineers and problem solvers who have a passion to design and optimize systems and processes that impact our lives. Besides mathematics and science, they have outstanding business and social skills that also help them evaluate the impact of their engineering solutions on the business and people.

Vision for Research: The IE Department research thrust areas are in Operations Research, Human Factors, and Advanced Manufacturing. Application areas include supply chain, healthcare, entertainment, manufacturing, aerospace, energy, automotive, and many more. Faculty research has been supported by a variety of federal grants and industry contracts (e.g., NSF, DoD, ONR, NIST, NASA, FHWA, Toyota, GE Appliances/Haier). Further, the department has extensive interdisciplinary collaborations across several units at UofL, including Arts and Sciences, Social Work, Medicine, and Public Health, as well as with the other seven departments within the Speed School of Engineering.

Top Areas of Research.
• Advanced Manufacturing: mechanical, material, design, and industrial aspects of advanced manufacturing science and engineering
• Human Factors: human-machine interaction, cognitive engineering, computer usability, and human-AI-robot teaming
• Supply Chain and Logistics: forecasting, inventory, distribution, transportation, facility layout, and network design
• Operations Research and Decision Analytics: advanced algorithms for optimization, simulation, data analytics, predictive modeling
Dr. Lihui Bai, LoDI and Dept of Industrial Engineering

**SUMMARY**: With recent movement of electricity market deregulation, advanced market-based transactive demand management represents the future of efficient power distribution system. We employ optimization and data analytics for automated home energy management in a smart grid to flatten the electric load curve over time. Studies include determining optimal set point for HVAC system, optimal deployment of distributed HVAC controllers and characterization of price-responsiveness of electricity consumers. Through collaborating with the public utility of a mid-west municipality, the research team successfully designed and assessed a demand response field project featuring home battery systems, controls of smart appliances and a novel residential electricity rate structure.

Project funded by Tennessee Valley Authority through its Smart Energy Technology Program

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
SUMMARY: Historically and presently state transportation agencies collect years of windshield pavement survey in their visual evaluation system (VES). The emerging automated pavement survey uses technology known as Laser Crack Measurement System (LCMS). Asset management requires a mapping between the two evaluation systems, particularly using continuous LCMS measures in hundreds of features to predict VES scores on a Likert scale. Machine learning methods with decision tree classifiers, adaBoost-based ensemble and adaptive cross validation are used to achieve quality prediction. This work is a collaboration with the Division of Maintenance at the KY Transportation Cabinet, the state DOT of the Commonwealth. The agency looks to integrate the prediction models as they migrate asset management into the automated system.

Project funded by Kentucky Transportation Cabinet,
PI: Dr. Lihui Bai, Department of Industrial Engineering
Co-PI: Dr. Zhihui Sun, Department of Civil and Environmental Engineering

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
**Dr. Kevin Chou, Industrial Engineering**

**SUMMARY:** The laser powder bed fusion (LPBF) process is a layer-by-layer fabrication process that utilizes a laser to melt the powder layers to form desired parts. The surface morphology of parts made by the LPBF process is governed by the flow of the melt pool. The nature of the molten metal flow depends on the material properties, process parameters, and powder-bed particles, etc., and may result in potentially significant variations along a laser scanning path. These unknown characteristics pose difficulty in ensuring part quality and impedes adopting the laser powder-bed fusion to produce parts with delicate features. Dr. Kevin Chou’s research team is exploring the time-varying response of the temperatures and the molten flows in high-power laser scanning of metallic particles of stochastic distributions during short scanning. This work uses a discrete element method to simulate the powder particle spreading and multi-physics modeling to simulate the thermo-fluid phenomena during the single-track, multi-track and multi-layer scanning. During their early investigation, they have shown that the formation of the transient region at the beginning and end of the track is due to the inherent fluid flow governed by the thermo-capillary effect.

National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier

This research used the Additive Manufacturing Institute of Science and Technology core facilities at the University of Louisville and was supported by NSF Award # 1921263. Publication: Shrestha, S.; Chou, K., A study of transient and steady-state regions from single-track deposition in laser powder bed fusion. Journal of Manufacturing Processes, 61, pp.226-235.
SUMMARY: Organ trafficking networks have been severely under-researched compared to other trafficking or crime networks. There has been no published work that outlines comprehensive networks of organ trafficking. Prior case studies describe the complexity of organ trafficking networks. The system of such networks is comprised of multiple players, typically involving kidney sellers, buyers, transplant service providers, brokers and financial institutions that transfer money from kidney buyers to other actors. Inter-actor social networks are inherent in organ trafficking. However, no rigorous network analysis has been applied thus far to investigate the system. The proposed project: i) deploys Agent Based Model (ABM)-based simulations to delineate such networks based on limited but reliable data from the fields; ii) performs a network analysis on the simulated networks to investigate structural patterns of the networks; and iii) applies optimization methods to derive effective strategies to disrupt the networks.

This research is funded by the NSF grant: EAGER: ISN: Organ Trafficking: Network Analysis and Optimal Interventions for Disruption.

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
SUMMARY: Literature reports that both access to and outcomes of kidney transplants are worse among those patients with high degrees of blood type (ABO) incompatibility and antibody to donor human leukocyte antigen (HLA) incompatibilities. In these cases, undergoing desensitization as well as identifying a more compatible donor via Kidney Paired Donor (KPD) exchange is recognized as a novel promising approach. KPD exchange allows incompatible donor-patient pairs to swap donors with other incompatible pairs in the program. The approach to combine desensitization with KPD exchange is relatively new, and the selection of the patients to be desensitized and donor-patient matching after desensitization are performed in an ad-hoc manner rather than integrated in the KPD run. In this project we developed an optimization-simulation approach to optimally incorporating desensitization into a KPD exchange and evaluating the benefit of such an integration over time.

Project funded by EVPRI RII Grant

Dr. Arsalan Paleshi, Industrial Engineering

**SUMMARY:** The COVID-19 pandemic has had a major impact on how organizations operate their businesses all around the world. In particular, they have altered their operations to create a safer environment for their employees and customers. The Trager Institute (TI) at the University of Louisville provides multi-resource healthcare services such as primary care, geriatric, psychotherapy, wellness and acupuncture to senior patients in the Louisville metro area. As a consequence of the pandemic, it had to reduce its in-house services to the patients in the year 2020. In this study, we built a discrete-event simulation model using AnyLogic to help TI to plan its return to normal capacity. The model simulated the activities related to the services provided by the institute, the movements of the patients, service providers, and the staff of TI in its offices during the operating hours. The outputs of the study demonstrated TI’s busy hours during the day and the specific areas inside the institute that had the highest density of movements by people. The results of this study have served as a guide for TI to plan its in-house and tele-health services and schedule its employees’ activities in order to resume its operations in full capacity.

**Researchers:** Drs. Lihui Bai, Arsalan Paleshi, Monica Gentili and PhD student, Shahab Sadri

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
Dr. Pratik Parikh, Industrial Engineering

**SUMMARY**: Despite the rapid rise in online shopping, the vast majority of retail purchases are still made in physical, ‘walk around and look for it’ stores. In 2019, in-store purchasing was over 5 times higher than online purchasing (84% vs. 16%). The layout of a retail store directly affects which products shoppers are exposed to, and ultimately their purchase. Optimizing a layout to increase product visibility can directly benefit both the retailer (e.g., increased revenue) and the shopper (e.g., increased satisfaction). We proposed several layout design models that would help a retail designers increase shopper visibility of their products. We used shopper’s 3D field of view, layout and rack design factors, and product placement strategies to estimate visibility and the corresponding impulse revenue. Our findings suggest that shorter height, non-orthogonal rack placements, and slightly curved racks appear to substantially enhance shopper visibility. We expect our findings to benefit retail practice (a ≥$6 trillion industry), academics, and the society.

Project funded by U.S. National Science Foundation under grants CMMI#1548394.
SUMMARY: Researchers at the University of Louisville partnered with the US Department of Veterans Affairs (VA) to evaluate a tool that texts COVID-19 information and advice straight to veterans’ phones. The VA is using an automated short message service (SMS) application named ‘Annie’ as part of their COVID-19 response with a protocol for coronavirus precautions, which can help the veteran monitor symptoms and can advise the veteran when to contact their VA care team or a nurse triage line. We surveyed 1,134 Veterans on their use of the Annie application and coronavirus precautions protocol. Survey results support what is likely a substantial resource savings for the VA, as well as non-VA community healthcare. Moreover, the majority of veterans reported at least one positive sentiment (felt more connected to VA, confident, or educated and/or felt less anxious) by receiving the protocol messages. The findings from this study have implications for other healthcare systems to help manage a patient population during the coronavirus pandemic.

**SUMMARY:** In a common parking lot, much of the space is devoted to lanes. Lanes must not be blocked for one simple reason: a blocked car might need to leave before the car that blocks it. However, the advent of autonomous vehicles gives us an opportunity to overcome this constraint, and to achieve a higher storage capacity of cars. Taking advantage of self-parking and intelligent communication systems of autonomous vehicles, we propose puzzle-based parking, a high density design for a parking lot. We introduce a novel method of vehicle parking, which leads to maximum parking density. We then propose a heuristic method to solve larger problems, and mathematically prove that the method produces optimal results. To improve layout designs reducing vehicular movements, we propose a use of a local search integrated with a deep reinforcement learning method. Finally, to take advantage of these puzzle-based designs in large-scale, we propose a modular layout design.

This research is being conducted by Parag Siddique, PhD Candidate in Industrial Engineering, under the direction of co-advisors, Dr. John S. Usher, and Dr. Kevin R Gue.

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
Dr. Xiaomei Wang, Industrial Engineering

**SUMMARY:** Workload, burnout and interruption have long been important topics in the high-risk, time-constrained work domains such as healthcare. The COVID-19 pandemic has posed new challenges to the industry. Combining big data and mobile sensing technology may lead to better understanding of the problem and solutions.

Related research experience:

- Using electronic health record data to model patient-related workload in the emergency department, supporting improved patient assignment and workload management
- Interruption recovery of supervisory task under a command and control setting
- Using smart watch and mobile app to track and detect stress for college student and veteran with PTSD
- Fatigue and sleep quality measurement in the offshore oil and gas industry using multidimensional methods

Potential topics: interruption recovery, COVID-19 burnout, multi-method workload assessment

**SUMMARY:** Artificial intelligence (AI) and machine learning (ML) have recently received tremendous attention from the entire scientific community. Much has been done in applying them to different work domains. However, many AI and ML-based systems are black boxes to the human users which causes trust issues. Understanding the human-AI-Robot interaction is essential to applying such tools in the real world. Dr. Wang has conducted a human-in-the-loop study to evaluate methods of explaining ML predictions to end users, and to understand the usage patterns of a ML-based decision support system. Participants had diverse levels of knowledge on machine learning and showed different reasons for trust/distrust on the ML-based system. This work opens up broad topics as shown in the figure that a successful human-AI-robot system must be evaluated on performance, satisfaction, trust and safety dimensions.

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**Understanding and Evaluating Human-AI-Robot Interaction with considering different dimensions**


Dr. Li Yang, Industrial Engineering

**SUMMARY**: The mechanical behaviors of the finite-size cellular structures manufactured via advanced manufacturing such as additive manufacturing (AM) often exhibit significantly different characteristics compared to the classic cellular design theories, which was largely attributed to the local heterogeneity with both the material (e.g. defects, anisotropy) and the structural boundary conditions (e.g. constraints, free surfaces). In this project, an analytical model based on the classic stiffness matrix-based description was employed for the full-scale modeling of finite-size cellular structures with local heterogeneity, in order to ultimately establish fundamental knowledge of the comprehensive material-unit cell topology-structure-property relationships for non-ideal cellular structures. Some preliminary results have revealed various insights into the elastic and fracture failure of cellular structures with brittle (perfectly elastic) materials that are expected to have broad impact in the area by re-calibrate the traditional knowledge base.

**Publication from this project:**
Logistics and Distribution Institute (LoDI)
The Logistics and Distribution Institute at the University of Louisville (http://uofllogistics.org/) is a multi-disciplinary research institute under the Office of Vice President of Research and Innovation and currently housed in the Speed School of Engineering. The institute is dedicated to improving the practice of logistics across a variety of industries (e.g., manufacturing, 3PL service, and health care). It was formed in 1998 to serve as the organizational entity required to bring together the strong individual and university resources that had been engaged in conducting research, teaching, and solving problems relating to logistics and distribution.

**Vision:** The mission of the Institute is **improving the practice of logistics, producing research, and preparing students to be leaders in their fields.** To achieve this mission, we have the following goals:

- Increase intra-university and inter-university collaboration in the activities of LoDI.
- Increase research and education in logistics and distribution.
- Attract students to participate in research in logistics and distribution.
- Assist the local and global community and industry with logistics and distribution problems

**Top Areas of Research**

- Healthcare logistics
- Supply Chain and Logistical Planning
**SUMMARY:** This project aims to assist public utility companies to determine the optimal locations and capacity planning for public charging networks in urban as well as regional transportation networks. The objective of the joint simulation-optimization model is to maximize charging convenience for EV users while taking into account daily traffic demand, state of charge, waiting time for charging, and population and business growth. Through collaborating with UofL research team, LG&E and KU is able to make recommendations on optimal sites for charging stations in Louisville metro area as well as in the regional highway systems.

Project funded by NSF I/UCRC Center for Efficient Vehicles and Sustainable Transportation Systems (EV-STS)

**LoDI Research Thrust Areas**
- Healthcare logistics
- Supply Chain and Logistical Planning

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)

SUMMARY: The problem of access to primary care may become exacerbated as projections through 2025 suggest visit volume growth will outpace the supply of new PCPs partly due to an aging population. Accordingly, primary care patient panels are expected to grow in size (i.e., number of patients), which will likely lead to physician burnout.

This project aims to balance workload of PC physicians within a healthcare network. The research establishes the statistical evidence for replacing a nonlinear and probabilistic overflow frequency with a utilization function. Thus, the optimization model focuses on minimizing system-wide total deviations from provider’s nominal load. This is achieved by re-assigning patients among providers within the network.

In view of the ease of implementation as well as quality and continuity of care, The model allows practitioners to specify movement of patients between physicians are not allowed for certain patients. Examples include those 1) have 2 or more chronic conditions; 2) with an age > 65; 3) prefer not to move for other reasons;

LoDI Research Thrust Areas
✓ Healthcare logistics
• Supply Chain and Logistical Planning

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
Understanding Barriers to Living Kidney Donation

Dr. Monica Gentili, LoDI and Dept of Industrial Engineering

**SUMMARY:** Policymakers, transplant programs, end-stage renal disease (ESRD) patients, and other members of the transplant community have a vested interest in increasing living organ donation. Despite several introduced policies to increase the number of living organ donors living kidney donation comprised only 30% of kidney transplants in the United States in 2019. Additional research on the motivation and values influencing one’s decision to become a living donor is urgently needed. In this project we apply a mixed-methods study using both qualitative and quantitative tools to answer complex questions to understand barriers to living donation. We are 1) conducting semi-structured interviews to transplant donors as well as transplant candidates, sampled from the transplants processed at the UofL School of Medicine, and 2) applying artificial intelligence (AI) methods to extract and catalog sentiments and perception towards living donation from user comments in news articles published on the web.

Project funded by EVPRI Transdisciplinary/Multidisciplinary Collaboration Research Planning Grant (TCRPG)

**LoDI Research Thrust Areas**
- Healthcare logistics
- Supply Chain and Logistical Planning

This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
Motivated by issues dealing with delivery of emergency medical products during humanitarian disasters, in this project we address the general problem of delivering perishable items to remote demands accessible only by helicopters or drones. Here each drone operates out of platforms that may be moved when not in use and each drone has a limited delivery range to service a demand point. Associated with each demand point is a disutility function, or a cost function, with respect to time that reflects preferred delivery clock time for the demanded item, as well as the item’s perishability characteristic that models nonincreasing quality with time. We first address the problem of locating the platforms as well concurrently determining which platform serves which demand points and in what order – to minimize total disutility for product delivery. In a second scenario we consider the two-period problem where the platforms can be relocated, using useable road network, after the first period. Extensive computational experiments, using different drone delivery ranges as well as different drone fleet sizes, provide valuable insights on the performance of such drone delivery systems.

LoDI Research Thrust Areas
- Healthcare logistics
- Supply Chain and Logistical Planning


This research used the core facilities at the University of Louisville Logistics and Distribution Institute (LoDI)
Mechanical Engineering
Dr. Thomas Berfield, Mechanical Engineering

Summary: This project focuses on the power generation associated with buckled-beam stability switching, specifically within a torque-arm actuated vibration scavenging device. Compressive residual stress levels within a PE-CVD produced layer of silicon nitride are tailored to induce buckling of a piezoelectric-coated central beam into an “S” shape. Torque arms mounted with tip masses are used to transfer vibration loads to the central beam, inducing switching between stable shapes and large energy-generating strains in the piezoelectric layer. Results have demonstrated entry of this device into a high-energy dynamic regime under chirp excitation, while operating at low driving frequencies (below 100 Hz). The high-energy orbitals associated with common, ambient environment vibration levels can produce energy sufficient to power inaccessible distributed sensor networks, such as for structural health monitoring of underground water supply lines.
Solid-State Refrigeration using Colossal Barocaloric Effect in Plastic Crystals

Dr. Bikram Bhatia, Mechanical Engineering

SUMMARY: Solid-state cooling devices offer the potential to significantly improve air conditioning and refrigeration efficiency, which currently account for about a quarter of our total energy demand. Recent studies have demonstrated extremely large barocaloric responses (temperature change resulting from hydrostatic pressure) in several materials systems, including plastic crystals, that far exceed the responses from other caloric materials and rival the performance of existing vapor compression cooling systems that are inefficient, difficult to scale down and have a high global warming impact. As part of this work, we have developed novel experimental platforms for characterization of barocaloric properties of solid-state materials materials (including plastic crystals such as neopentyl-glycol) and device designs that address the challenges associated with achieving large hydrostatic pressures and delivering and removing heat from the solid-state refrigerant materials. We believe this work will enable the realization of practical, solid-state cooling systems for next-generation HVAC and refrigeration systems with markedly superior performance compared to current cooling technologies.

National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier

This research used the core facilities at the University of Louisville Conn Center and the Micro Nano Technology Center, and was supported by NASA Kentucky award# 80NSSC20M0047 and UofL EVPRI RII Grant.
SUMMARY: Nature has provided great insights to create innovative materials with enhanced mechanical properties. Common examples of biological structural materials, including nacre, glass sea sponge and bones, feature exceptional high strength damage tolerance while maintaining light weight. In this work, inspired by the multiscale configuration of the microstructure of cork, we designed a new type of lightweight architected composite structure with multilayered arrangement of hard brittle and soft flexible phases. The experiment shows that energy absorption of this novel architected material increased four times compared with conventional cellular structure under the compressive strain up to 70%. The cyclic loading test reveals that the proposed architecture possesses exceptional shape recoverability under the compressive strain of 40%. The deformation mechanisms demonstrated here are robust and applicable to other architected cellular materials across multiple length scales and suggest new ways to design lightweight and high-resilience structural materials.

This research used the core facilities in AMIST and was supported by Start-up fund from the Department of Mechanical Engineering. Publication: H. Jiang; L. L. Barbenchon; B. A. Bednarcyk; F. Scarpa; Y. Chen, “Bioinspired multilayered cellular composites with enhanced energy absorption and shape recovery” Additive Manufacturing 36 (2020): 101430.
Harnessing Fractal Cuts to Design Lattice Metamaterials for Energy Dissipation

Dr. Yanyu Chen, Mechanical Engineering

**SUMMARY:** Lattice metamaterials with three types of cuts were designed and manufactured by 3D Polyjet printing technology. Three-point bending tests and DIC analysis were combined to investigate their bending behavior. Experimental results show that the structural ductility can be enhanced sharply by increasing fractal levels while keeping their shape recoverability. Though energy absorption and dissipation obtained from bending tests are significantly different, their loss factors are very close. This is attributed to the hybrid effect of friction and viscoelasticity. Results suggest that bending depth has a neglectable effect on the bending stiffness and loss factors while there exists a power scaling law between bending stiffness and sample thickness. The findings reported here solidify the idea that sliding friction and viscoelastic damping together influence energy dissipation capability.

Work performed at University of Louisville’s AMIST. This research was supported by NASA KY Space Grant and the start-up fund from the Department of Mechanical Engineering at the University of Louisville.
Dr. Kunal Kate, Mechanical Engineering

**SUMMARY:** The Powder Fused Filament Fabrication (PF³) process is a hybrid fused filament fabrication (FFF) process that uses a ceramic/metal-powder polymer filament that is 3D printed. Subsequently, the part undergoes binder removal by debinding and densification by sintering at elevated temperatures. Dr. Kunal Kate’s research team addresses current knowledge gaps in PF³ material processing that prevent consistent printing and advanced engineering materials, and 3D printed structures with desirable microstructures and properties. As a representative example, they have shown bimodal particles’ use in engineering novel composites microstructures with 80 wt.% loaded PF³ 3D printing Hydroxyapatite (HAp) and HAp + 10 wt.% Si₃N₄ composites. This work advances the fabrication of medical implants of custom strength with tailored geometries that are patient-specific and addresses gaps in the traditional press-and-sinter manufacturing process limited to making simple geometries like discs and plates.

National Research Priority: NSF 10 Big Ideas on Future of Work at the Human-Technology Frontier

This research used the core facilities at the University of Louisville Conn Center and the MicroNanoTechnology Center and was supported by NSF Award # NSF IIP 1450730. Publication: Sudan, K.; Singh, P.; Gökçe, A.; Balla, V. K.; Kate, K. H., “Processing of hydroxyapatite and its composites using ceramic fused filament fabrication (CF³)” Ceramics International 2020.
Dr. Badri Narayanan, Mechanical Engineering

**SUMMARY**: All solid lithium sulfur battery (ASLSB) is a promising next-generation energy storage technology for electric transportation due to its high theoretical capacity (5-6 times higher than Li-ion), enhanced safety, and natural abundance of sulfur. Despite this promise, ASLSBs remain far from commercialization due to unresolved issues at the electrode-electrolyte interfaces that lead to loss of contact, poor Li ion conduction or pre-mature cell shorting. The daunting challenges in ASLSBs arise primarily from a lack of fundamental understanding of interfacial processes, especially at atomic to mesoscopic scales. Dr. Narayanan’s research group bridges this knowledge gap and address the interfacial issues by developing highly accurate materials models at atomic-to-mesoscopic length/time scales using data-centric and machine learning (ML) methods. As a representative example, in collaboration with scientists at Argonne, he developed ML models to accurately predict the energetics of organic molecules using his dataset of thermodynamic properties of 133,000 small molecules from high-level quantum-chemical (G4MP2) calculations. This newly developed ML model can retain the predictive power of quantum chemistry for large organic molecules, for which G4MP2 calculations are not tractable. Such models open new avenues to predictively design electrolyte/electrode additives to achieve high-performance ASLSB interfaces.

**National Research Priority: Department of Energy Vehicle Technologies**

High-level quantum chemical database of 133,000 molecules

Machine learning models developed from a large G4MP2 dataset (a) show excellent predictive power (b) even for large molecules (c) for which G4MP2 calculations are not tractable. The newly developed ML models (SchNet and FCHL Delta) show better accuracy than low-fidelity quantum calculations (B3LYP).

SUMMARY: This study presents the structural and electrochemical effects accompanying the growth and stabilization of a porous iron oxide nanolayer on LiMn$_2$O$_4$ relative to a control in the environment of an aqueous lithium-ion battery. Two coinciding mechanisms are provided to explain the growth of the PION layer, both of which require favorable electrolyte conditions. The unconventional way in which the PION layer is grown from within a sealed test cell allows for changes in electrochemical activity of the underlying LiMn$_2$O$_4$ to be observed with respect to PION growth in a pseudo-transient fashion. The PION layer is found to reduce degradation of the LiMn$_2$O$_4$ surface by preventing the formation and growth of undesirable Li$_2$MnO$_3$, thereby reducing material strain and manganese dissolution into the electrolyte. The PION layer is also found to preserve the pristine structure of LiMn$_2$O$_4$ to a significant degree and hinder the growth of mass and solid electrolyte interface resistances by passivating the electrode/electrolyte interface. Additionally, the PION layer provides a significant reduction in charge transfer resistance between the electrode and electrolyte phases and superior bulk lithium diffusion kinetics. Together, these improvements lead to significantly increased levels of structural and electrochemical stability over the control and allow the PION cell to enhance or preserve its electrochemical characteristics over a test-span of 500 deep discharge cycles.

National Research Priority: NSF 10 Big Ideas on Growing Convergence Research

CV profiles vs cycle number of the Control and PION full cell configurations is shown in (A) and (B) respectively. The arrows shown indicate the direction of increasing cycle number, as does the darkening of shading (lighter colors indicate fewer cycles run and darker colors correspond to greater cycles run). EIS profiles of both full cells in their pristine and uncycled state are shown in (C), while the EIS profiles of each cell after 500 deep discharge cycles is shown in (D) with an enhanced view of the same data shown inset to provide more clarity.

This research used the core facilities at the University of Louisville Conn Center was supported by NSF Award # NSF 1624712. Publication: N. Schuppert, S. Mukherjee, A. Bates, J.Jasinski, S. Lee, and S.Park Energy Storage, DOI: 10.1002/est2.143.
Dr. Chris Richards, Mechanical Engineering

**SUMMARY:** The technical contribution of the research is the implementation of anti-windup compensation for constrained attitude stabilization of spacecraft nominally controlled by adaptive controllers. The inspiration for adaptive control is to address common problems that arise in flexible spacecraft: shifting modal vibration frequencies, actuator uncertainties, deployment of payload, non-uniform fuel distribution, fuel sloshing and the incursion of unanticipated vibration modes. Moreover, to address likely scenarios of saturating actuators throughout ascent/descent, anti-windup compensation is implemented to assist the adaptive controller. The theoretical framework for both stability analysis and design is developed for this novel control architecture. The research is motivated, in part, by the need to meet tighter landing zone tolerances and to manage rendezvous and proximity operations between ascent/descent vehicles and orbiting spacecraft. The research builds upon two funded collaborative research projects between the principal investigator and NASA Marshall Flight Space Center, namely, resolving discontinuities in linear time-varying Space Launch System model simulation and anti-windup architectures for landers and ascent vehicles.


SUMMARY: Solid-state lithium (Li) batteries, using superionic solid conductors to replace liquid electrolytes, show advantages of high safety and high specific capacity of Li metal (3860 mAh/g). In such battery structure, solid electrolytes (SEs) and interfaces play significant roles to achieve high battery performance. Dr. Hui Wang’s research team focus on new SEs materials synthesis and address on interface instability issue in solid-state Li batteries. As representative examples, they have developed a simple and economic liquid-based method to synthesize lithium argyrodites (Li$_7$PS$_6$ and Li$_6$PS$_5$X, X=Cl,Br,F) and studied the strategies to construct stable interface between sulfide SEs and electrodes. This work advances new synthesis methods for popular solid electrolytes and understanding of interfacial reactions, promoting the development of high performance of solid-state batteries.

National Research Priority: DOE Priority—Advanced Batteries for Vehicle Technology

This research used the core facilities at the University of Louisville Conn Center and was supported by DOE Award #EE-0008866. Publications: W. Arnold, D. Buchberger, Y. Li, M. Sunkara, T. Druffel, H. Wang, “Halide doping effect on solvent-synthesized lithium argyrodites Li6PS5X (X= Cl, Br, I) superionic conductors”, Journal of Power Sources, 2020, 464, 228158; Y. Li, W. Arnold, J. Jasinski, A. Thapa, G. Sumanasekera, M. Sunkara, B. Narayanan, T. Druffel, H. Wang, Interface stability of LiCl-rich argyrodite Li6PS5Cl with propylene carbonate boosts high-performance lithium batteries, Electrochimica Acta, 2020, 363, 137128.
Parallel Dielectric Spectroscopy of Individual Particles using Isomotive Dielectrophoresis

Dr. Stuart Williams, Mechanical Engineering

**SUMMARY:** This work designed, fabricated, and tested a microfluidic chip that applied an AC electric field to suspended particles. The induced dielectrophoretic forces would result in particle translation; the dielectric properties of individual particles could be extracted based on their frequency-induced trajectory. The novelty of this device was the unique curvature of the etched sidewall electrodes to produce a uniform electrokinetic force. A combination of precise deep reactive ion etching and anodic bonding was needed for successful fabrication of this microfluidic chip. Results demonstrated that isomotive dielectrophoresis was feasible and capable of conducting single cell dielectric spectroscopy. The throughput of this device is one to two orders of magnitude greater than the current technique for multi-frequency single-cell spectroscopy, electrorotation (several cells per minute compared to a few cells per hour).

National Research Priority: NSF 10 Big Ideas on Growing Convergence Research

Micro/Nano Technology Center
MicroNanoTechnology Center (MNTC)

Dr. Kevin Walsh, Faculty Director

UofL built its first cleanroom in 1997, which was also represents the first-ever academic cleanroom in the state of Kentucky. The original MNTC was a small 1,500 sq ft class 100/1000 facility in Lutz Hall. Due to high usage and the growing worldwide interest in the fields of nanotechnology and nano-science, UofL expanded its program and constructed a new $30M state-of-the-art 10,000 sq ft facility in Shumaker Research Building in 2006. In 2015, the UofL MNTC was selected to be part of the prestigious NSF-funded national nanotechnology network (www.nnci.net). The NSF NNCI contains 16 site universities with the best nanotechnology fabrication and characterization core facilities in the USA.

Vision The MNTC core facility is state-of-the-art “maker-space for everything and anything small”. The MNTC provides internal and external users from a wide variety of disciplines with the expensive equipment and professional expertise to perform cutting edge research and educational training in the interdisciplinary fields of nanotechnology, microelectronics, MEMS (microelectromechanical systems), microfluidics, bioMEMS, and optics. The MNTC also serves as a vital university catalyst for start-up companies, educational training, and economic development in the region.

Top Areas of Research
• Nanotechnology and nano-science
• MEMS – microelectromechanical systems
• Sensors and actuators
• Semiconductors, microelectronics, and solar
• Microfluidics, optics, and bio-MEMS
SUMMARY: Experience in the following areas

- General microfabrication
  - Photolithography
  - Physical vapor deposition
  - Plasma etching
  - Wet chemical etching
  - Thermal processing
- CMOS fabrication
  - Photo diodes, germanium infrared sensors
- Nano drug delivery
  - Encapsulation of ATP in vesicles for accelerated wound healing
  - HPLC for characterization of nucleotides
- Synthetic cell membranes
  - Electrophysiology measurements
  - Membrane protein characterization
- Computational cell biology
  - Modeling retrotransposon life cycle
  - Metabolic modelling

A) Prototype of a custom photodiode
B) Self organized aluminum structures observed in an electron microscope
C) Electrical activity of an ion channel protein
D) HPLC measurement of nucleotides from a cell extract
3D Printing of Microscale Structures using Greyscale Lithography

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**SUMMARY:** Greyscale Lithography is a process of creating complex 3D structures in photoresist using rapid modulation of UV light during exposure. The amount of photoresist exposed and removed from the surface of the substrate is directly correlated to the amount of light used during lithography. By rapidly fluctuating the intensity of light we are able to create relatively complex 3D structures via photoresist. We can then transfer these structures to a more stable material, either through using it as a mold or using the Bosch process in a Deep Reactive Ion Etcher to copy the structure into the silicon underneath the photoresist.

Profilometry images produced using Zygo white light interferometry showing dome structures along with staircase and pyramid sample structures. All images are of AZ4620 photoresist.

This research used the core facilities at the University of Louisville Micro NanoTechnology Center.