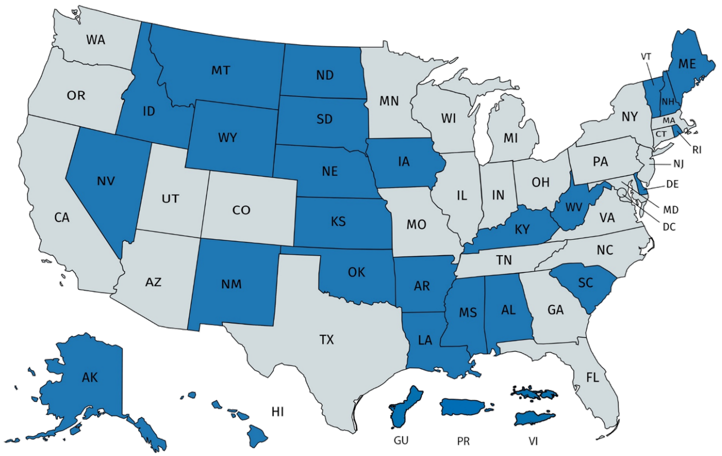
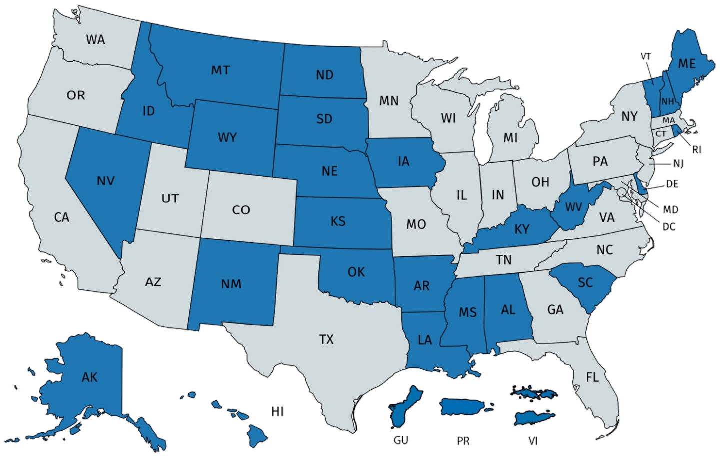
NASA EPSCoR Virtual Research Discussions with Stennis Space Center

A Companion Booklet created for NASA and EPSCoR Researchers in conjunction with the "NASA EPSCoR Virtual Research Discussions with Stennis Space Center" meeting held on February 9, 2023, from 3:00-4:30 pm Eastern



Topic Area 1

Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications



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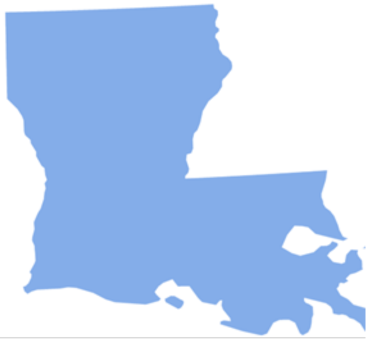
January 27, 2023



Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Integrated Degradation and Remaining Useful Life Assessment

Dr. Michael Khonsari

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Michael Khonsari is Dow Chemical Endowed Chair and Professor of Mechanical Engineering at LSU. Before joining LSU in 1999, he was on the faculty of The Ohio State University, University of Pittsburgh, and Southern Illinois University. He also served as a research faculty fellow at NASA, Department of Energy, and Wright-Patterson Air Force. Khonsari's research background is in the areas of tribology (the science of friction, lubrication, and wear), fatigue and fracture, and modeling and simulations of machinery. He has published 3 technical books and over 430 archival papers and book chapters. Khonsari is a fellow of National Academy of Inventors (NAI), American Association for Advancement of Science (AAAS), American Society of Mechanical Engineers (ASME), and Society of Tribologist and Lubrication Engineers (STLE).

Integrated Degradation and Remaining Useful Life

PI/POC: Michael Khonsari
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DESCRIPTION

Current strategies for structural health management and degradation neither reveal information on the evolution of damage/aging nor offer an effective determination of the remaining useful life.

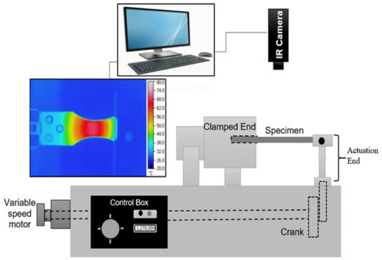
The premise of this investigation is that material degradation is a consequence of the disorder that accumulates with time and is responsible for aging. Thus, evolution of aging due to degradation can be monitored by examination of disorder via entropy.

OBJECTIVES

- ❖ Develop framework to reliably assess degradation and materials life-expectancy
- ❖ Pioneer a material degradation framework for anticipating looming failure
- ❖ Devise a methodology to predict the remaining life of materials
- ❖ Develop methodologies for assessing health of NASA's ground and space assets

EXPERIMENTAL TESTING AND MODELING

- ❖ Load-cycle and operating stress evaluation
- ❖ Non-destructive entropic damage accumulation
- ❖ Online health monitoring



TECHNICAL APPROACH

All degradation processes are irreversible, produce entropy with evolving defects that continues to increase until failure occurs.

The onset of failure is associated with the maximum accumulated entropy beyond which failure occurs.

Our team has pioneered an experimentally verified framework for degradation analysis that uses the concept of entropy to reliable forecast aging. This is a unified approach to assess the heath of systems due to aging caused, for example, by fatigue, wear, corrosion, erosion, etc. The approach is particularly useful for monitoring health of systems. Further, it enables one to perform accelerated testing to forecast the life expectancy of current and future systems.

CAPABILITES, EXPERIENCE, RESOURCES

- ❖ Testing and laboratory demonstration for materials of interest
- ❖ Sensing, accelerated testing, and evolution of remaining life
- ❖ Demonstration of reliable results for degradation such as fatigue life prediction
- ❖ Demonstration of reliable results associated with wear and tear degradation
- ❖ Demonstration of application to complex substances such grease lubricated machines
- ❖ Ten US patents on related technologies

State-of-the art facilities are available in PI's laboratories for fatigue, friction and wear, and component testing such as bearings, gears, and seals.

PI is the director of Center for Innovations in Structural Integrity Assurance (CISIA) and Center for Rotating Machinery (CeRoM)

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Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Leveraging "Digital Twining" to Enhance System Health Monitoring

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Farzad Ferdowsi, Ph.D., is an Assistant Professor in the Department of Electrical & Computer Engineering and also a faculty member of UL's Energy Efficiency and Sustainable Energy Center (EESE) within the Energy Institute of Louisiana (EIL). Ferdowsi received his PhD from Florida State University in 2016 and was a Research Associate/Lecturer at LSU from 2017 to 2018 before he joined UL Lafayette in Aug 2018. He is currently a full member of the College of Engineering Graduate Faculty. He served on the faculty senate for 2020-21 and 2021-22 AYs. Ferdowsi is actively involved in research and is currently supervising four (3) PhD and two (2) MS students. He has secured over $2M of external funds since 2018 as a PI and Co-PI on several research projects. Ferdowsi's research interests include smart and connected energy systems, energy efficiency, and energy resilience.

Intelligent Integrated System Health Management (ISHM)

Leveraging "Digital Twining" to Enhance System Health Monitoring

Digital Twin of Power & Energy System

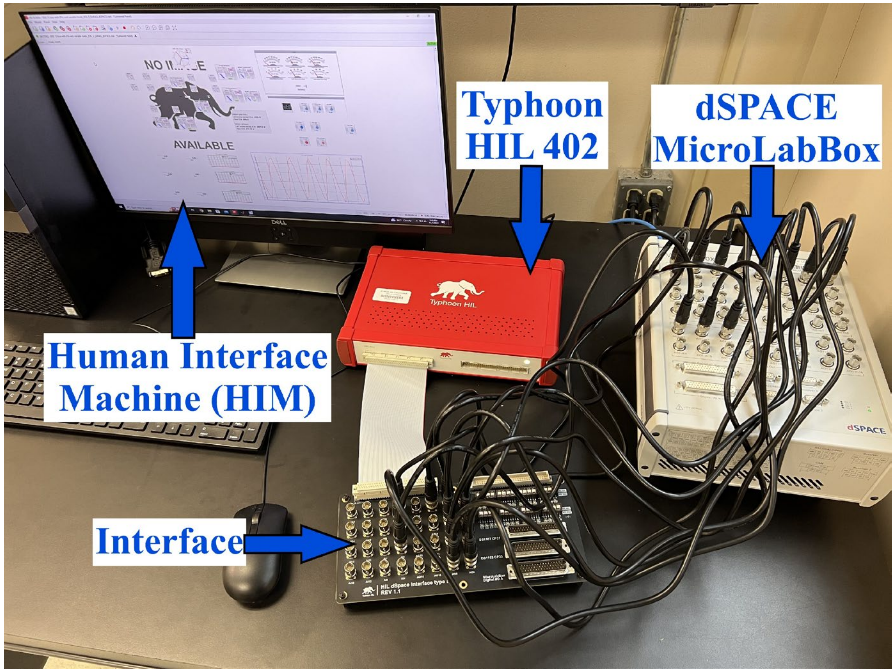
→ What-if scenarios → Prognostic

→ Symptoms → AI → Diagnostic

- Real-time measurement
- Maintenance data

- Disturbances
- Intentional faults

- Safer for the System
- More Accurate Testing



Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Structural Integrity Monitoring System using Autonomous Unmanned Aerial and Ground Vehicles

Han-Gyu Kim, PhD

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Han-Gyu Kim is an Assistant Professor in the Department of Aerospace Engineering at Mississippi State University (MSU). His research expertise is in advanced composite materials and structures for hypersonic vehicles, multiscale and multi-physics modeling, structural dynamics, fracture mechanics, fatigue and nondestructive damage evaluation. For hypersonic vehicle design, he has been collaborating with the Air Force Research Lab at the Wright-Patterson Air Force Base for the last eight years. Dr. Kim is currently working with the NASA Glenn Research Center to develop an efficient experimental framework and a high-fidelity damage model for composite structures. His recent effort is focused on developing a structural integrity monitoring system using autonomous unmanned aerial vehicles (UAVs) in collaboration with Raspet Flight Research Laboratory at MSU. For this project, Dr. Kim is employing the latest sensing systems and UAVs such as a LiDAR system RIEGL VUX-240 (link), a motion capture system with twelve Primex 41 sensors (link), aerial cameras iXM 100MP (link), and UAVs Teros-C (link) and TigerShark-XP (link). For UAV application, he developed a maneuverable 3D digital image correlation technique which does not require a spatial calibration process.

STRUCTURAL INTEGRITY MONITORING SYSTEM USING AUTONOMOUS UNMANNED AERIAL AND GROUND VEHICLES

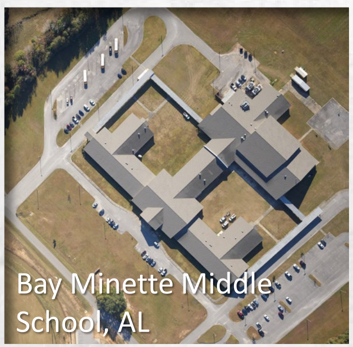
MOTIVATION: A maneuverable, unmanned and autonomous system is needed to monitor the structural integrity of ground facilities, spacecraft, rovers, habitats and landers

OBJECTIVE: In-situ damage detection and structural integrity analysis from cloud point spatial data and digital images acquired using unmanned aerial or ground vehicles (UAVs or UGVs) with LiDAR scanning and 3D digital image correlation (DIC)

Object Identification using LiDAR → Autonomous Path Planning → Digital Image Acquisition → Image Analysis & Correlation → Structural Integrity Analysis

UAV

Aerial Image



3D Point Cloud from LiDAR

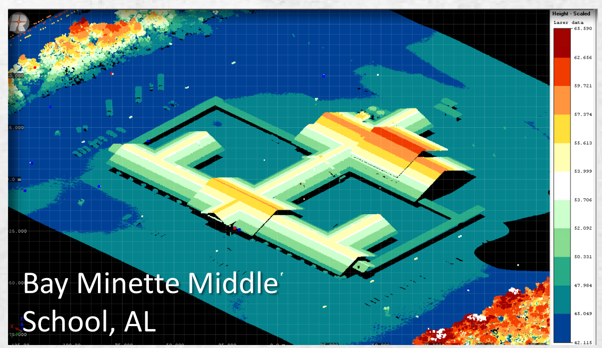


Image Acquisition using UAVs

STEP 1: LiDAR system on an UAV or UGV → 3D point cloud of an object

STEP 2: Spatial information of the object → Autonomous path planning for UAVs and UGVs

STEP 3: Formation flight of UAVs and UGVs for image acquisition around the object

STEP 4: 2D image analysis for surface damage detection & 3D DIC for structural health monitoring

MISSISSIPPI STATE UNIVERSITY™

Han-Gyu Kim, PhD
Department of Aerospace Engineering

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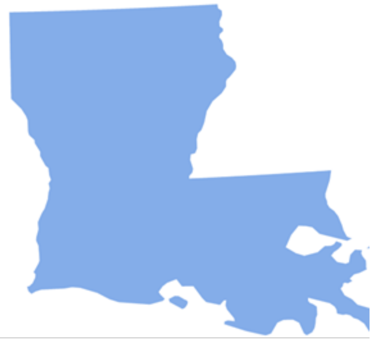

Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Integrated AI-based Deficiency in Control Systems

Dr. Md Tamjidul Hoque

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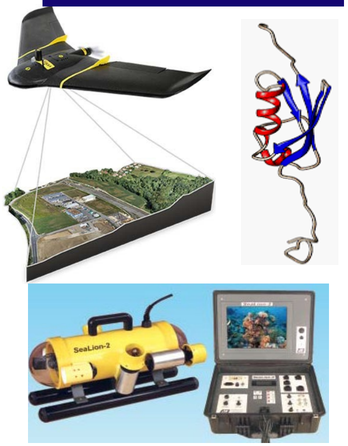
Md Tamjidul Hoque is an Associate Professor of Computer Science at UNO. He is the Director of the BML Lab and Coordinator for the Machine Learning (ML) and AI Concentration as well as Graduate Certificate in ML & AI. His research expertise is at the Deep/Machine Learning Modeling and Algorithm Designing, Computer Vision, Natural Language Processing (NLP), Autonomy, Unmanned Aerial/Surface/Underwater Vehicle, Big data and Data Science, Bioinformatics and Evolutionary Computation. Since 2004, Dr. Hoque's primary focus of his research is to develop integrated machine learning solutions and research tools toward Intellectual Property Data Analysis and Decision Support Using Advanced Text Analytics (for NASA/SSC), Prediction of Increased Risk Based on Available Safety, Quality and Maintenance Data (for NASA/SSC), Drone Image based Levee Fault Detection and System Integrity and Health Monitoring (for USACE), AI-Based Identification of Deficiencies in Flood Control Systems (Azure/Microsoft), Machine Learning for Flight Terminal Procedure Chart Change Detection for Possible Threat (for NRL), and techniques for large-scale biomedical research towards predictive health analytics.

Integrated AI-based Deficiency in Control Systems

Collect Data



Data

Data

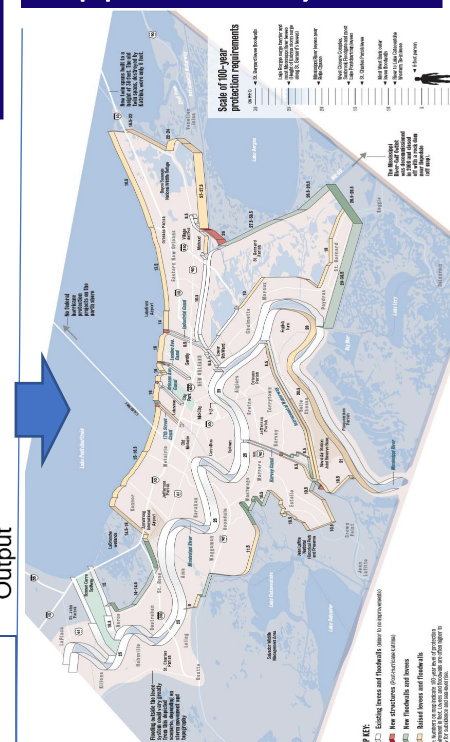
Curation,
Generation,
Augmentation,
Sampling,
Transformation
Labeling.

SMOTE | GAN | AE

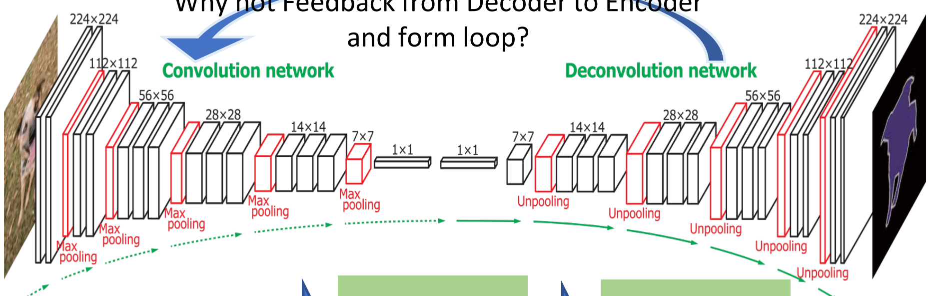
Problem Domain

Natural Language P.
Computer Vision
Bioinformatics
Anomaly Detection
System Integrity
Explainability

App: Levee System



Model Development



Deep Model → Tangent Kernel → Kernel Machines

No Free Lunch Theorem → Stacking

Optimized & Robust Model

Evolutionary Optimization

Swarm Optimization

Parameter Minimization

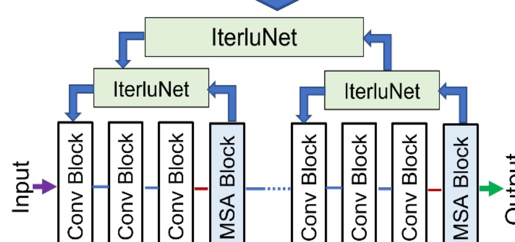


Fig: Combining our Iterative Loop U-Net (IterLUNet) with multi-head self-attentions (MSAs) and ConvNet of AlterNet.

Bioinformatics & Machine Learning Lab

Dr. Md Tamjidul Hoque

Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

A Graph-Based Architecture for Anomaly Detection on The Edge

Davide Guzzetti

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Dr. Davide Guzzetti is an assistant professor in the Department of Aerospace Engineering at Auburn University. His research group has experience with a variety of optimization tools (e.g., gradient-based, indirect, machine learning, and population-based meta-heuristics) that are employed in mission analysis and development of spacecraft autonomy. The group is also actively engaged in Pre-Phase A and Phase A feasibility studies for space missions. Dr. Guzzetti operates a room-scale, free-roaming VR facility that is organically integrated with system engineering, spacecraft autonomy, immersive analytics, and mission design research. Dr. Guzzetti's program has been supported by NASA, AFRL, and private companies. Dr. Guzzetti has been recognized as a NIAC 2020 fellow, an Auburn University Outstanding Graduate Student Mentor, and an alumnus of the Italian honor society Alta Scuola Politecnica. He is also a current member of the Space Flight Mechanics Committee of the American Astronautical Society. He obtained a Ph.D. in astrodynamics from Purdue University in 2016 and holds a Master's degree in space engineering from Politecnico di Milano, Italy.

An Architecture for Anomaly Detection on The Edge

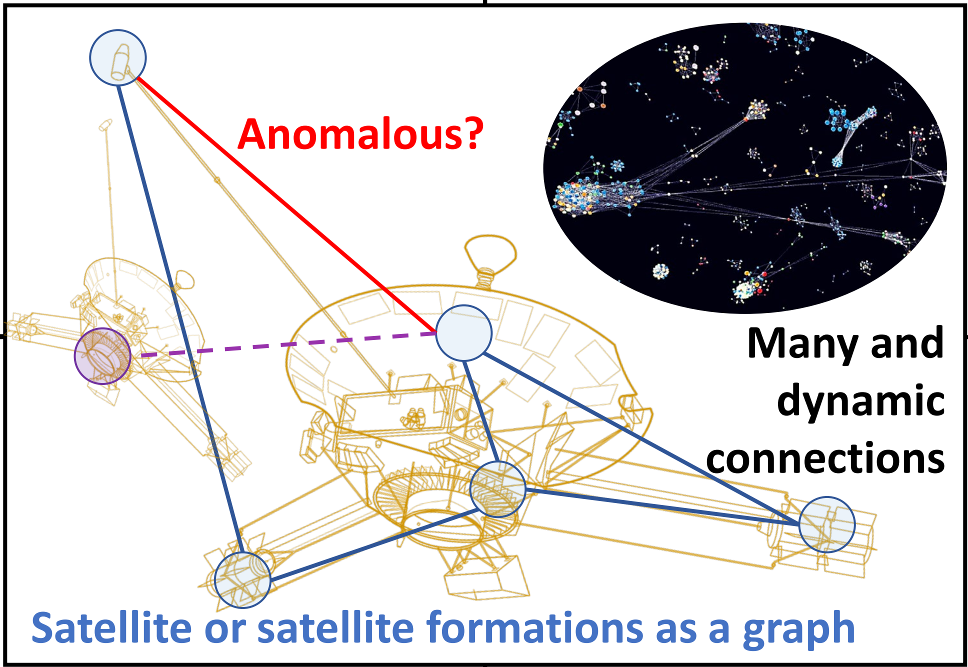
Application and challenges

Challenges in monitoring single elements in large dynamic systems include: **(1)** variety of dynamic anomalies; **(2)** limited operator availability compared to the system size; **(3)** limited on-board computational power;

and **(4)** higher latency, inefficient use of system throughput, and stale data when process is centralized.

Objectives and Outcomes

1) Demonstrate modelling of a space vehicle as a dynamic graph of interconnected subsystems
2) Demonstrate anomaly detection performance for a transformer-based network in simulation environment
3) *Long-term:* Demonstrate performance on a bread-board prototype



Milestones

We demonstrated a transformer-network-based anomaly detector for anomalous edge detection on dynamic graphs, ones that can represent the local connections observed by a network node. This architecture offers a small computational footprint for on-edge implementation while being naturally designed to classify spatio-temporal pattern variations.

Figure (Left). *A satellite system is a network of interconnected subsystems.* ***Inset.*** *Dependency network in 3D (figure by Boumghar at al.). Colors represent different spacecraft subsystems.*

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Topic

Intelligent Integrated System Health Management (ISHM) for Ground and Space Application

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Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Development of an Improved Visualization Tool for the Assessment of Climate Change Impacts on Mississippi Sound Coastal Waters using Integrated NASA Satellite and a Novel Autonomous Surface Vessel Collected Field Datasets

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Dr. Padmanava Dash is an Associate Professor in the Department Geosciences at Mississippi State University (MSU). He specializes in remote sensing and water biogeochemistry. His broad research interests include investigating the conditions under which water quality issues develop, assessing their ecological impacts, and developing visualizations for their management and mitigation. His research includes field, laboratory, Unmanned Aerial Systems (UASs), and satellite remote sensing approaches to study harmful algal blooms, suspended sediments, colored dissolved organic matter (CDOM), acidification, pathogens, nutrients, toxic elements, and heavy metals to enhance the current state of knowledge on detection and mapping of water quality parameters and thus support federal, state and coastal community efforts to manage human health and fisheries. Two water quality visualization tools developed by his group can be accessed at

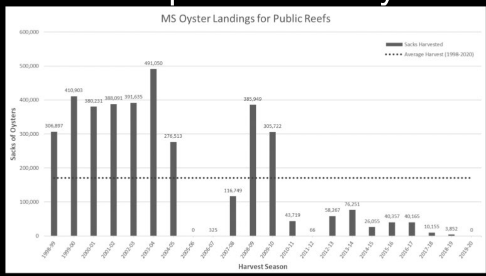
https://www.water.geosci.msstate.edu/

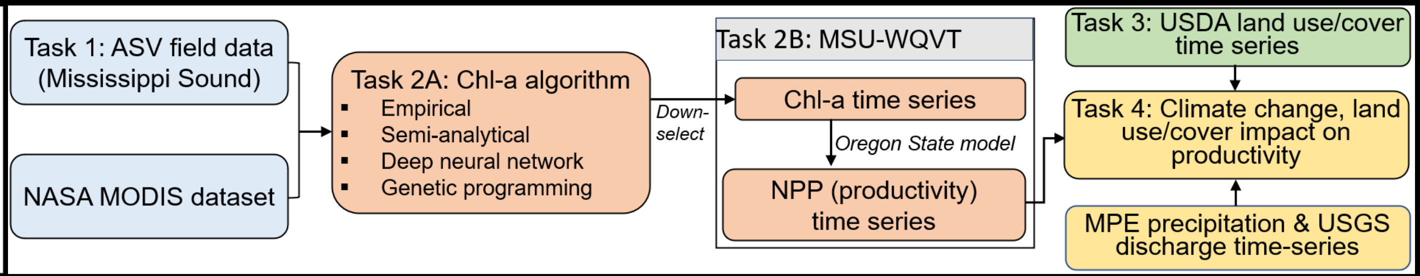
https://www.water.geosci.msstate.edu/monitor/

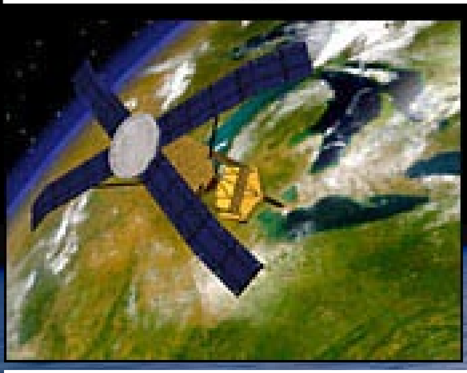
Development of an Improved Visualization Tool for the Assessment of Climate Change Impacts on Mississippi Sound Coastal Waters using Integrated NASA Satellite and a Novel Autonomous Surface Vessel Collected Field Datasets

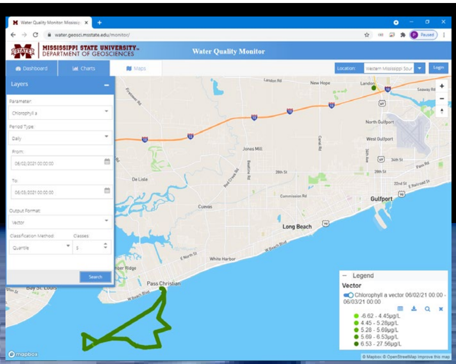
Padmanava Dash, Associate Professor, Department of Geosciences, Mississippi State University

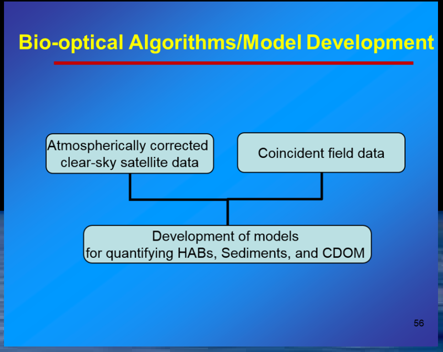
- SSC Research Topic: Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications
- Motivation: Declining fisheries productivity
- Tools: Satellite sensors, Autonomous Surface Vessels, & Water quality visualization tool
- Applications: Use of data from NASA's Earth-observing satellites to tackle tough challenges and develop solutions that improve our daily lives

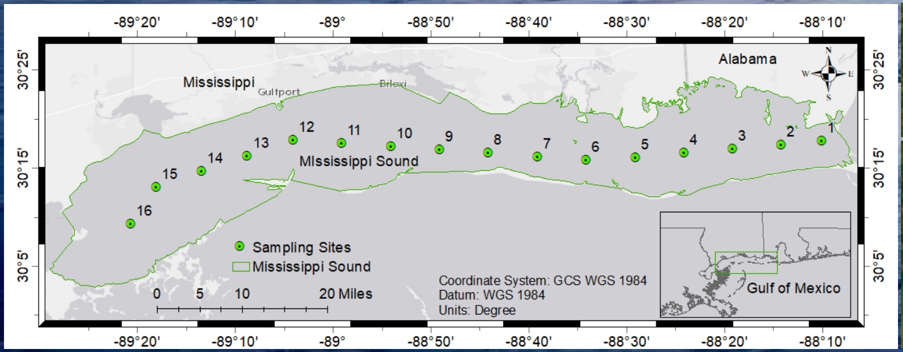


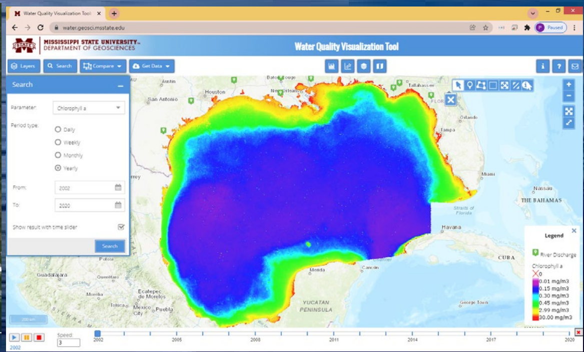












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Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Lithium-Ion Batteries Online Health Assessment and Health-Aware Environment-Aware Charge and Discharge Control

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Jaber Abu Qahouq is a Professor of Electrical and Computer Engineering at The University of Alabama (UA). He's the director of The Energy and Power Electronics Systems and Devices Laboratory. Dr. Jaber's main current research focus is in power electronics and energy systems field including architectures, controls, circuits/electronics topologies, energy storge systems management, electric vehicles, renewable energy systems, health diagnosis and prognosis, and wireless power transfer, among others. Dr. Jaber applies his expertise in power electronics and energy systems to wide range of applications.

THE UNIVERSITY OF ALABAMA ENGINEERING

Lithium-Ion Batteries Online Health Assessment and Health-Aware Environment-Aware Charge and Discharge Control

SSC Priority Topic: ISHM

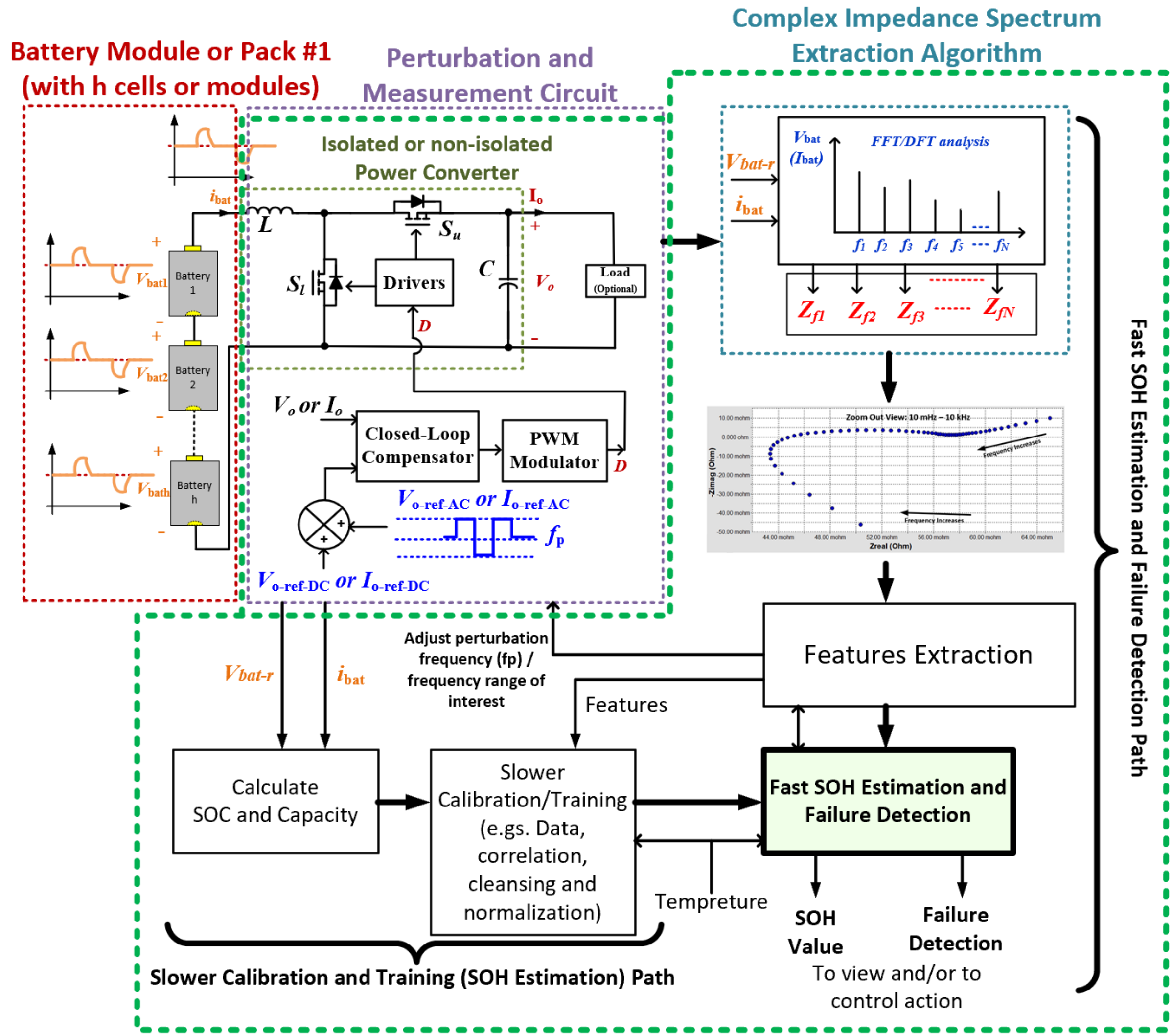
The Energy and Power Electronics Systems and Devices Laboratory

Capabilities and Research:

- Develop power converter control which allows for online measurement of battery complex impedance spectrum while still achieving voltage/current/power regulation with no operation interruption.
- Utilize health indicators from the measured impedance of lithium-ion batteries to diagnose and estimate their health and capacity as they age and under varying environmental conditions.

Outcomes:

- Heath-Aware and Environmental conditions-Aware autonomous utilization (charge and discharge) of batteries.
- Autonomous health management for longer life cycle.
- Advanced monitoring and potential failure prediction for risk reduction.



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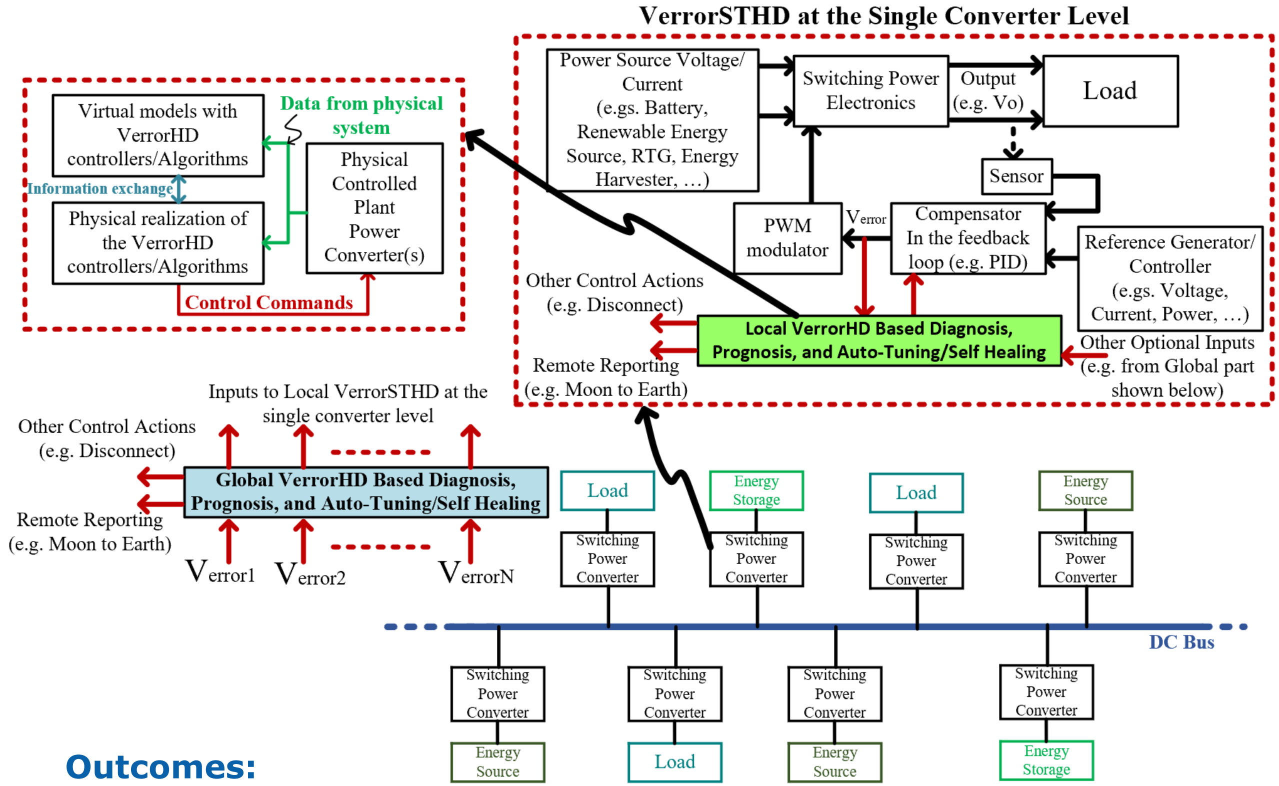
ENGINEERING

Power Converters Control Online Health Management/Diagnosis and Auto-Tuning for Interoperability
SSC Priority Topic: ISHM

The Energy and Power Electronics Systems and Devices Laboratory

Capabilities and Research:

- Utilize new online indicators for power converter control stability diagnosis that are readily available in the system and easy to measure for health management.
- No operation interruption of the power converter, power system, or loads.
- Indicators and algorithms are not based on and do not depend on conventional rule of thumb control design criteria that have their limitations and shortcomings (e.gs. Do not depend on gain margin and phase margin and root-locus design criteria).
- Health is diagnosed and managed as components age, components values change for example due to temperature variations, and as source or load characteristic change.



Outcomes:

- Maintained control stability performance and failure risk reduction with interconnected power converters and varying energy sources and loads operating under varying environmental conditions and age at different rates.
- Support self-healing and autonomous operations for the future of NASA exploration and space missions.

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Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Continuous, Autonomous, Machine-Learning-Enhanced Monitoring of Enclosed Fluid Systems for Ground and Space

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Caitlin Howell is an Associate Professor of Biomedical Engineering at UMaine. Her research expertise is in the detection, understanding, and control of biological and chemical phenomena at interfaces. She specializes in the control of biological contaminants relevant to human health such as bacteria and fungi. Since beginning at UMaine in 2016, Dr. Howell has developed strong ties with Maine legacy paper industry and mass-manufacturing partners and has been exploring the use of these cost-effective materials in technical applications such as biological and chemical compound sensing as well as microfluidics.

Continuous, Autonomous, Machine-Learning-Enhanced Monitoring of Enclosed Fluid Systems for Ground and Space

Motivation

Controlling Quality in Fluid Systems is Critical

Current Methods are Time-Intensive

Equipment is Fragile and Expensive

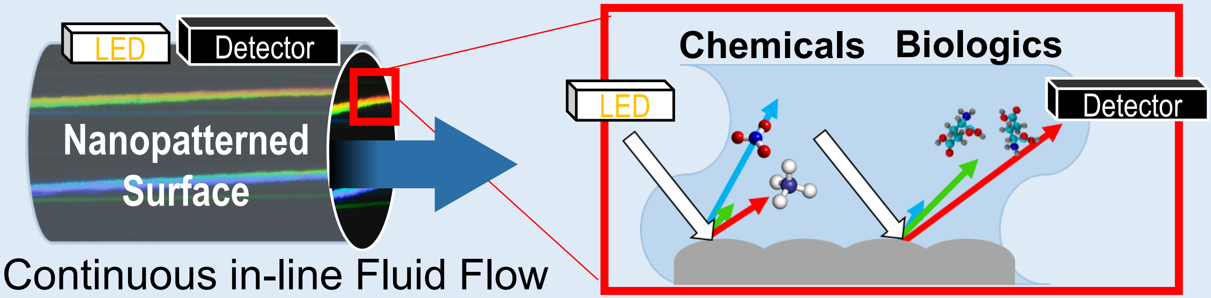
Low-Cost Industrial Diffraction Technology

Nanopatterned Diffraction Film

Mass-Manufactured

Lightweight and Flexible

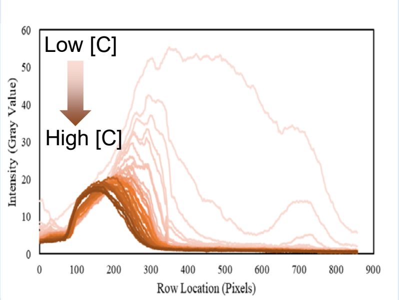
Our Research:
Use of Diffraction for In-Line Low-Cost Sensing of Fluids



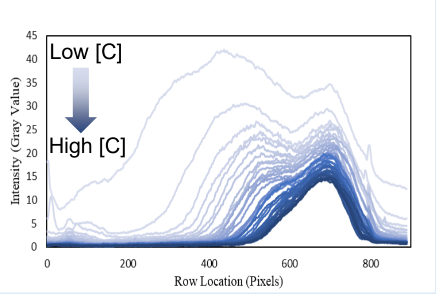
Continuous in-line Fluid Flow

Increasing Concentration

Red Contaminant

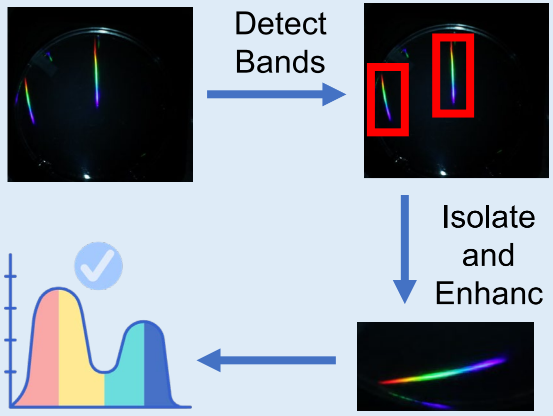


Blue Contaminant



Machine Learning-Enhanced

Regions-based Mask R-CNN (ResNet 50) Classification



Result:

Easily repaired, highly **adaptable system** for a wide **variety of fluid monitoring applications**

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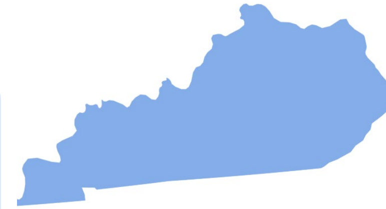


Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Intelligent Integrated System Health Monitoring and Fault-Tolerant Operation for Electric Propulsion Drivetrain Systems

Dr. JiangBiao He

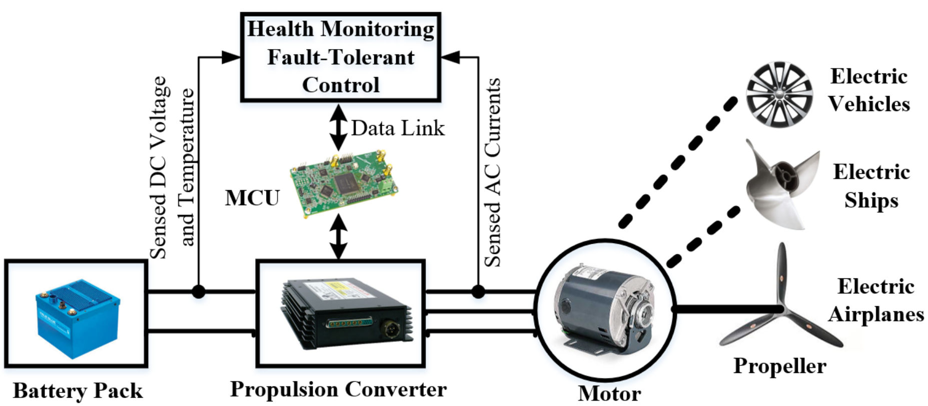
University of Kentucky
Department of Electrical and Computer Engineering
AMPERE Laboratory
Jiangbiao.he@uky.edu; (859) 257-3124

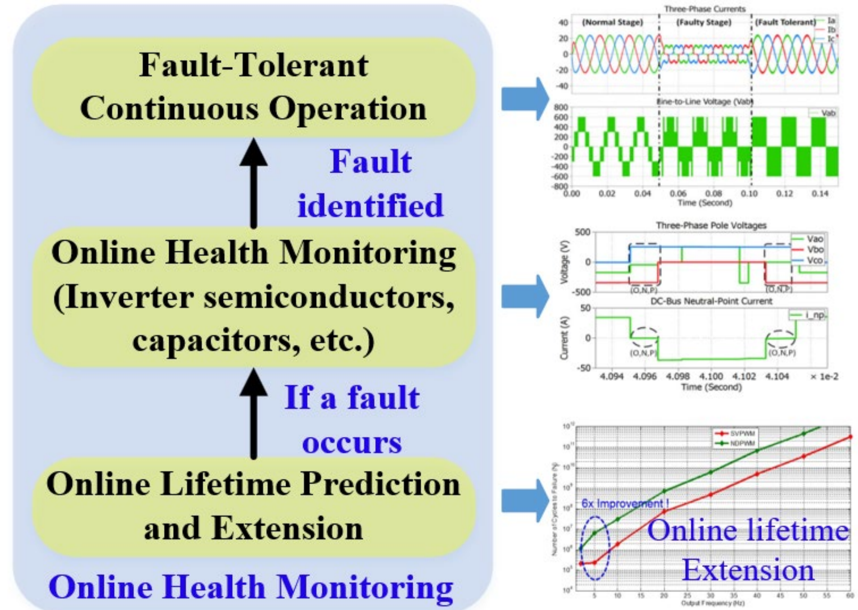
JiangBiao He is a tenure-track Assistant Professor and the endowed L. Stanley Pigman Faculty Fellow in the Department of Electrical and Computer Engineering at the University of Kentucky. He obtained his Ph.D. in Electrical Engineering from Marquette University, Wisconsin. He has worked in multiple large industry R&D centers, most recently as a Lead Engineer at GE Global Research in Niskayuna, New York. Prior to joining GE in 2015, Dr. He was employed with Rockwell Automation as a power electronics engineer, focusing on the product development of regenerative servo motor drives. He was also employed with Eaton Corporate Research & Technology in 2013 working on high-efficiency SiC power converters. Dr. He's research interests over the past 15 years include high-performance power electronics and motor-drive systems, and the related online health monitoring. He is the author/coauthor of more than 125 peer-reviewed technical papers and 10 U.S. patents on these topics.

Intelligent Integrated Health Management for Electric Propulsion Drivetrains

UK's electric power program has 55 years of history

Dr. He's R&D experience at GE and Rockwell





Our proposed intelligent integrated health management framework for powertrains can:

- Conduct prognosis and diagnosis
- Achieve fault-tolerant operation
- Low cost, high accuracy, and good scalability

University of Kentucky

Dr. JiangBiao He

NASA EPSCoR Research for SSC
January 27, 2023

Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Multi-scale Wireless Sensor Networks for Environmental and Human Health Monitoring

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Raju Badireddy is an Associate Professor in the Department of Civil and Environmental Engineering and Material Science Program where he maintains an active research program in Water Treatment and Environmental Nanotechnology. He is an environmental engineer, with expertise in nanotechnology-enabled microsensors for environmental and biomedical applications, water and wastewater treatment, resource recovery, membrane processes, contaminant sensing and remediation, and microscale-remote sensing using enhanced darkfield hyperspectral imaging microscopy.

Intelligent Integrated System Health management (ISHM) for Ground and Space Applications (Sub-topic: Advanced Wireless Sensors)

Dr. Raju Badireddy, University of Vermont

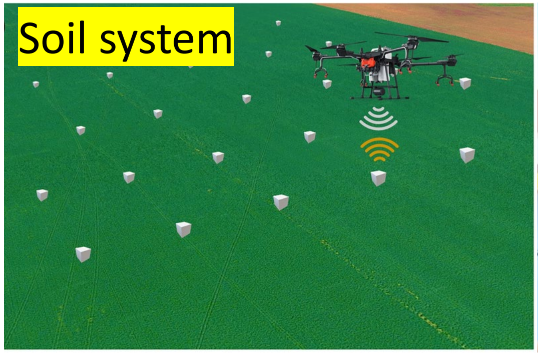
Key Aspects

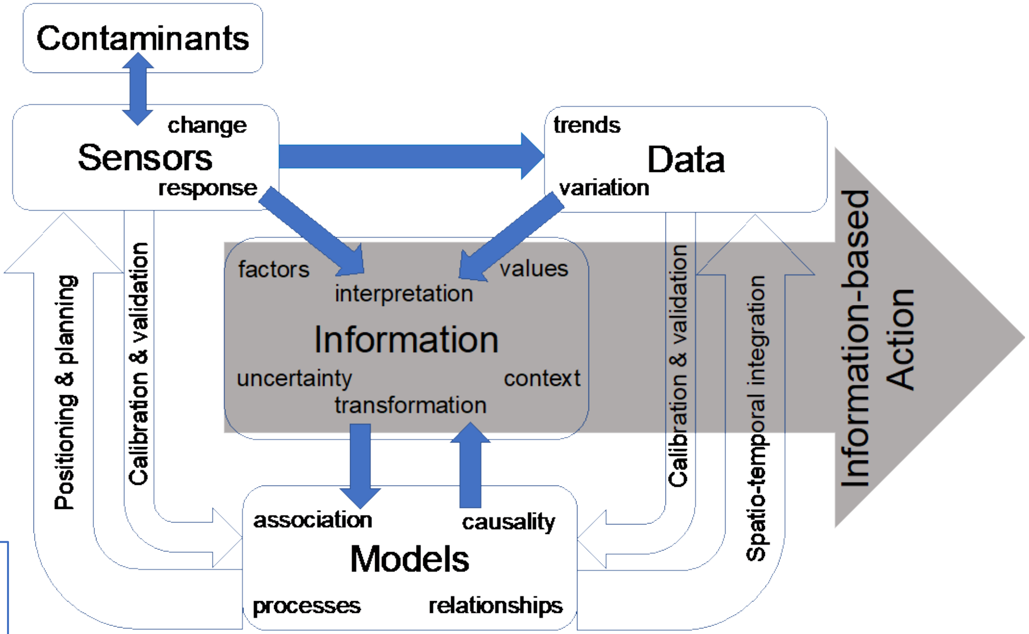
Multiscale Environmental Sensor Arrays Systems (MESAS) Group

- System health sensors (Aligns with SSC priority area)
  - ➢ Radiofrequency (corrosion, structural health, moisture content, etc)
  - ➢ Flexible force sensors to monitor stresses and strains due to physical movement
- Environmental sensors
  - ➢ Electrochemical
  - ➢ Optical
  - ➢ Nano-scale HSI (Vis-NIR-SWIR)

Inkjet printers, 3D Direct Ink Writing, and microcircuit board printer

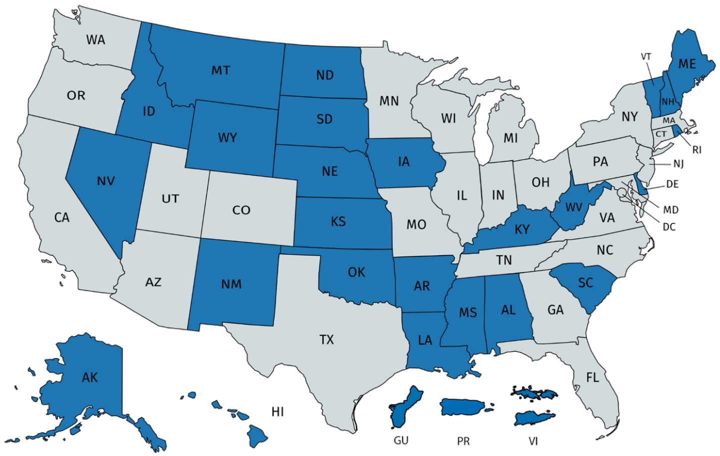
Research Capabilities





Topic Area 2

Advanced Propulsion Test Technology and Test Instrumentation



Advanced Propulsion Test Technology Development

Prediction of Dynamic Loading Generated by Two-Phase Cryogenic Fluid Flow

Dr. Shanti Bhushan

Associate professor, Department of Mechanical Engineering
Associate Director – CFD, Center for Advanced Vehicular Systems
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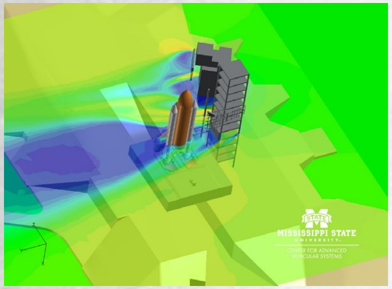
Shanti Bhushan is an Associate Professor of Mechanical Engineering at MSU, and also serving as Associate Director of CFD in Center for Advanced Vehicular System. His primary research is in the area of high fidelity CFD with emphasis in turbulent flow modeling and simulation. He has developed and validated novel turbulence/transition models to enhance robustness of CFD, for example, adaptive wall-function, algebraic model for Large Eddy Simulation that can account of energy backscatter, dynamic Hybrid RANS/LES model that provided physics-based blending of RANS and LES flows, and pressure-strain based marker for bypass transition onset predictions.

He has over twenty years of experience in the use of CFD for the prediction of complex fluid flow phenomena in aerodynamics, hydrodynamics, numerical weather prediction, bio-fluids and nuclear engineering applications. The proposed research will leverage his past experiences in development/advancement of Loci-Chem, a multi-physics solver for modeling chemically reacting multiphase high-speed flows, and two-phase flow predictions for ship hydrodynamics. He has contributed to the advancement of Loci-CHEM through implementation of advanced turbulence models, and development of fluid-thermal-structure interaction capability by coupling Chem with an in-house finite-element structure solver. He is also actively involved in validation of the solver for muti-species chemically reacting flow for Scramjet application.

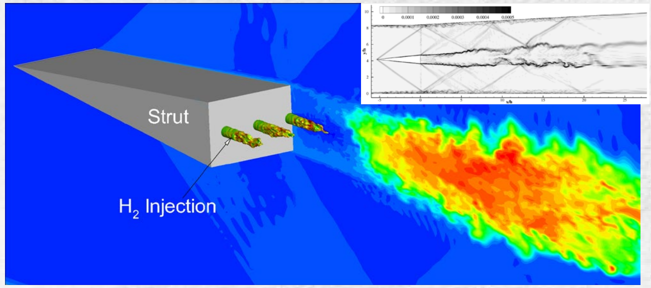
Prediction of Dynamic Loading Generated by Two-Phase Cryogenic Fluid Flow

Stennis Space Center (SSC) Area: Advanced Propulsion Test Technology Development

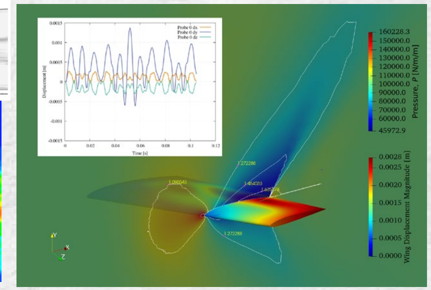
Existing Launch vehicle, propulsion, and missile systems analysis capability, Loci-CHEM



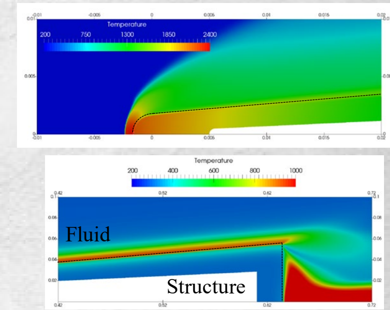
Compressible, Parallel General Purpose



Advanced turbulence, numerical methods; Muti-species reacting flow



Fluid-Structure Interaction (Flutter)



Thermal Soaking

Proposed: Two-Phase Cryogenic Flow Simulation Solver

Challenge: Cryogenic fluid undergoes phase change resulting in bubbly/plug flow in fuel lines.

Proposed Approach: Extend muti-species approach for two-phase simuation by implementing key physics.

Assumptions:

- Homogeneous, $u_g = u_l$
- Quasi-equilibrium, $T_g = T_l$
- No gravity

Equation of State:

Gaseous: $p_g = \rho_g R_g T$

Liquid: p_l, Stiffened EoS

$p = p_l + p_g$

Transport equations:

$\left.\begin{matrix}\rho_g \\ \rho_l\end{matrix}\right\}$ Species fraction; $\rho = \rho_g + \rho_l$

Momentum

Energy

Transport Properties:

$\mu = (\rho_g \mu_g + \rho_l \mu_l)/\rho$

$\kappa = (\rho_g \kappa_g + \rho_l \kappa_l)/\rho$

Phase Change Mass Flux:

- At wall, $f(T, T_w)$
- Each cell, $f(T, T_{sat}, P, P\_sat)$
- Mass source $S_g = -S_l$

Phase Change Heat Transfer:

- Latent heat generation/ absorption
- Wall heat flux $\dot{q} = f(T, T_w)$

MISSISSIPPI STATE UNIVERSITY

Center for Advanced Vehicular Systems CAVS

Advanced Propulsion Test Technology Development

A New Pathway for Prediction of Thermal Fluid Behaviors

Dr. Joonsik Hwang

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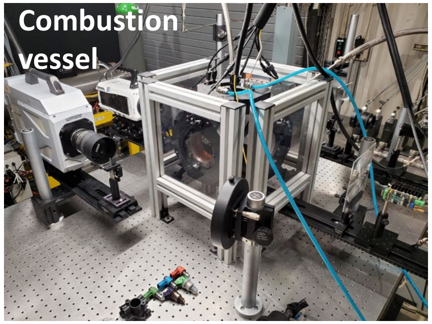
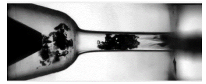
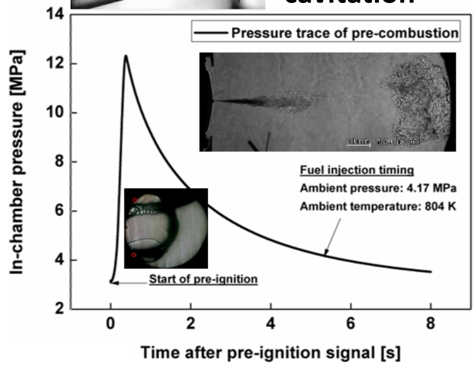
Joonsik Hwang is an Assistant Professor in the Department of Mechanical Engineering and Center for Advanced Vehicular Systems (CAVS) at the Mississippi State University. Before joining Mississippi State University, he had a post-doctoral fellowship at Sandia National Laboratories (Combustion Research Facility, Livermore, CA). He received his B.S. (2011), M.S. (2013), and Ph.D. (2017) degrees all in Mechanical Engineering at Korea Advanced Institute of Science and Technology (KAIST). His primary research specialization is in high-speed optical diagnostics of reactive thermal flows, advanced combustion strategy, Artificial Intelligence (AI) guided modeling and Computational Fluid Dynamics (CFD) simulation. He is leading various experimental/computational studies on thermal fluids at Advanced Propulsion and Spray (APS) Lab (https://apsl.me.msstate.edu/). The lab is equipped with high-pressure, high-temperature combustion vessel, high-speed camera, optical components (laser, lens, mirror, LED etc.), and a computational cluster. His lab also has access to High Performance Computing Collaboratory at Mississippi State University for CFD simulations.

A New Pathway for Prediction of Thermal Fluid Behaviors

Research Capability

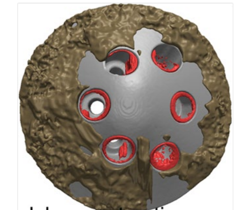




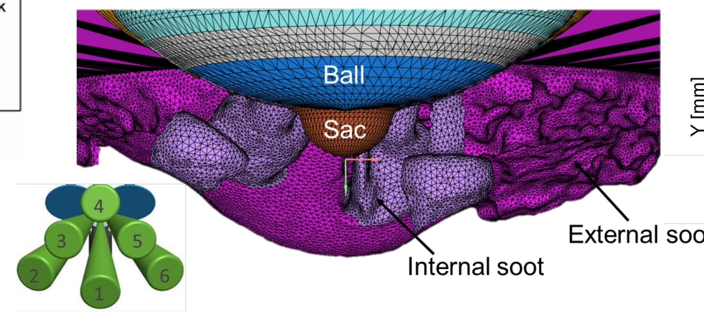


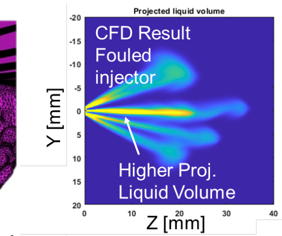
- We do "**QUANTITATIVE**" measurements on thermal fluid related to propulsion system using combustion vessel (boundary conditions are well controlled)

- We leverage CAVS' equipment for realistic CFD simulation. Here is an example of x-ray scanned fouled injector to investigate fluid-structure interaction.



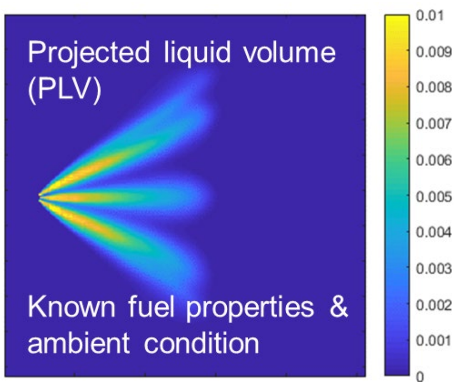
3D model reconstruction.
(Injector + inside soot + outside soot)





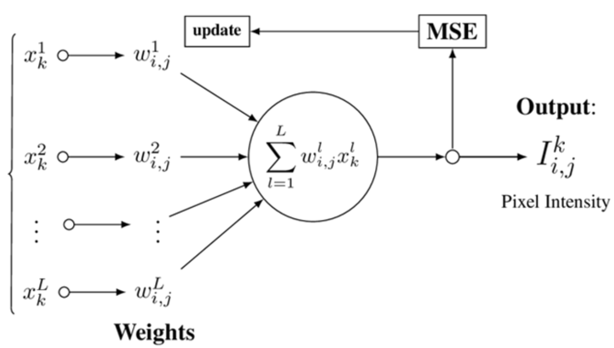
Experimental data

- Produce big experimental data with extended range of parameters.



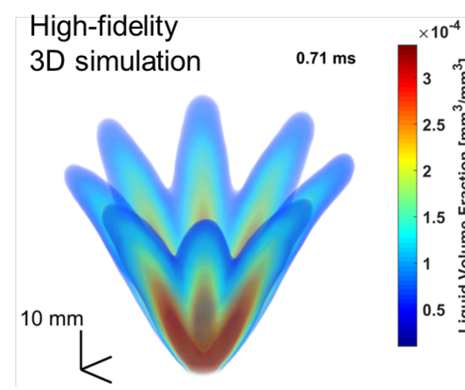
Data-driven (ML) models

- Build data-driven models by machine-learning (ML).
- Deliver net (~30KB size) to CFD



High-fidelity CFD simulation

- Validate/improve CFD results.
- Provide information that can't be measured in experiment.



Dr. Joonsik Hwang

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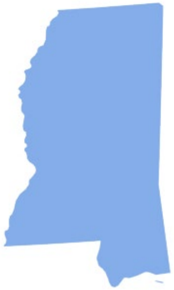

Advanced Propulsion Test Technology Development

Fluid-Structure Interaction and Fatigue Study of Vortex-Induced Vibration in Thermowells Subjected to Liquid Nitrogen Flow

Dr. Youssef Hammi

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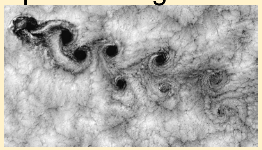
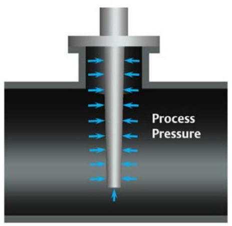
Dr. Youssef Hammi is currently an Associate Professor at the Mechanical Engineering Department and held positions as an Associate Research Professor at the Center for Advanced Vehicular Systems at Mississippi State University. Dr. Hammi’s research activities of particular interest encompass macromechanical/micromechanical constitutive modeling, inelastic behavior, damage, failure, fracture, fatigue, computational mechanics, discrete elements (DEM), user elements (UEL), Coupled Eulerian Lagrangian (CEL), finite element analysis (FEA), and Fluid-Structure Interaction (FSI). In a recent NASA project, Dr. Hammi performed two-way fluid structure interaction (FSI) simulations in ANSYS to simulate the flow around thermowells and its mechanical response. Stress distributions from the FSI simulations were then used to perform a fatigue analysis in the SIMULIA software fe-safe to evaluate the internal causes of failures due to fatigue. In fatigue analysis, bench-scale cryogenic fatigue testing at liquid nitrogen temperatures from the literature will be used to determine the fatigue properties of 304L and 316 stainless steel materials. Dr. Hammi is also interested and currently working in simulations using open-source FSI software.

Fluid-Structure Interaction and Fatigue Study of Vortex-Induced Vibration in Thermowells Subjected to Liquid Nitrogen Flow

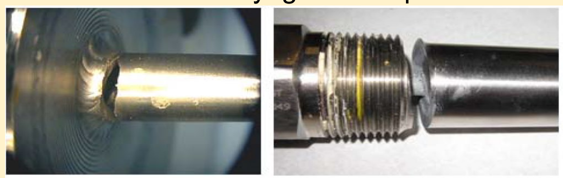
Motivation: Use Fluid-Structure Interaction (FSI) analysis to determine flow induced stresses and predict fatigue life in Alloy 304L and 316 Stainless Steel thermowells at cryogenic temperatures



Landsat 7 image of a von Karman Vortex Street [NASA]

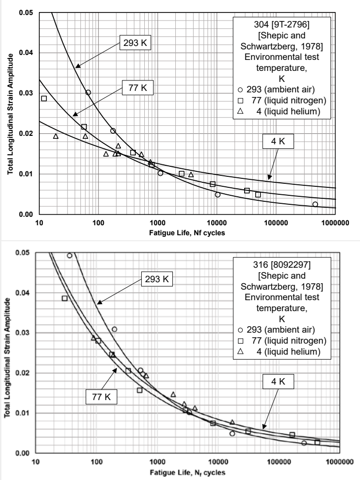


Thermowells



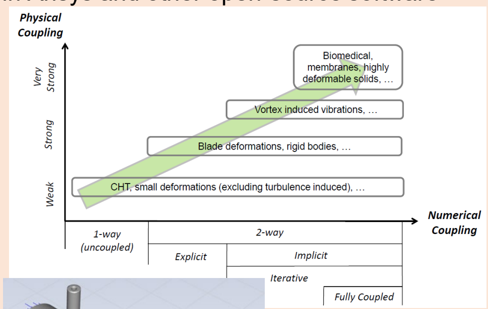
Examples of thermowell failures due to fatigue

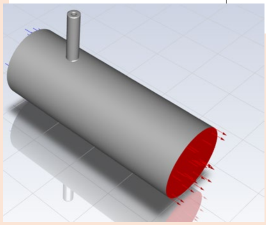
Experiment: 304 and 316 Stainless Steel Fatigue Data at cryogenic temperature



MTS Landmark Machine
Capacity: 100 kN

Modeling: Fluid-Structure Interaction approaches in Ansys and other open-source software

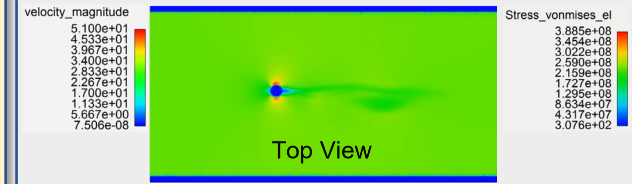


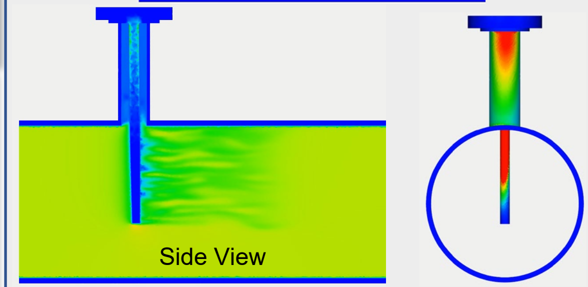


Boundary conditions (inlet and outlet) in the fluid region

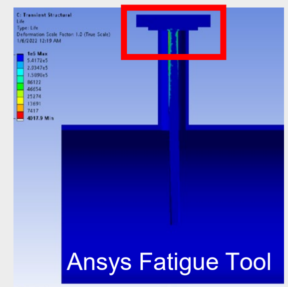
Simulation Results:

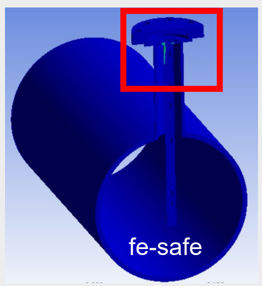
Fluid velocity (m/s) and stresses (Pa)





Fatigue life values in Ansys and fe-safe





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January 27, 2023

Advanced Propulsion Test Technology Development

Experimental characterization of cavitating flow in liquid rocket propellants

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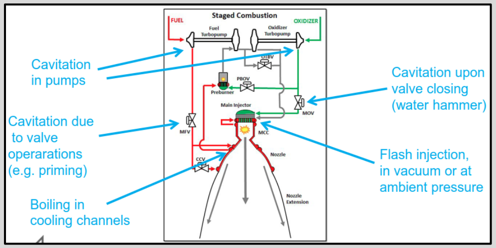
Shyam Menon is an Assistant Professor of Mechanical Engineering at LSU. He leads the Energy and Propulsion laboratory at LSU which is engaged in a variety of investigations of multiphase flows with application to fuel-based generation of energy and propulsion power for aerospace applications. EPL has developed capabilities to investigate multiphase (gas/liquid/solid) flows at low- and high-speed and reacting- and non-reacting conditions using scaled experimental setups and non-intrusive diagnostics including laser-based techniques. Ongoing projects are looking at swirl-combustion of Sustainable Aviation Fuels (SAF) for aircraft propulsion (DOE funded), particle-laden flow interaction with material surfaces (NSF and ONR funded), shockwave interaction with liquid and nanofluid droplets, and hybrid rocket combustion studies through temperature measurements and detailed numerical simulations.

Experimental characterization of cavitating flow in liquid rocket propellants

SSC Area of Research Interest : *Advanced Propulsion Test Technology Development*

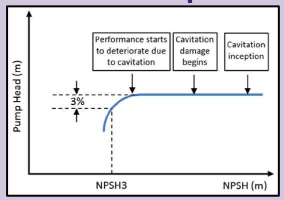
Motivation



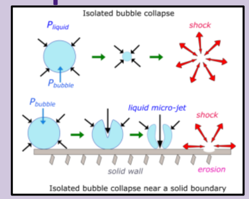
Cavitation of liquid rocket engine (LRE) propellants (LOx, LNG) occurs when local pressure drops below the vapor pressure, and is common in LRE's where cryogenic propellants are stored near their saturation point.

Bombardieri, C et al. (2017). Cavitation and multi-phase phenomena in liquid rocket engine systems.

Cavitation Impacts - SSC Propulsion Testing



Brennan, C, (1995), Cavitation and bubble dynamics



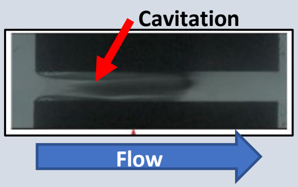
Sarkar, P. et al. (2018). 10th International Symposium on Cavitation

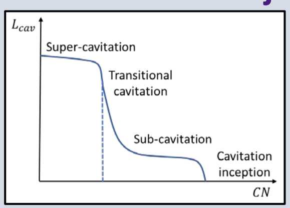
- Reduction in pumping capacity
- Decrease in head and pump performance
- Abnormal sound and vibrations
- Onset of flow instabilities including POGO
- Damage to pump parts : Erosion/Pitting; Mechanical deformation; Corrosion

Research Basis and Opportunity

- Turbopump inducer is designed to operate in slightly cavitation conditions for lighter propellant tanks/overall vehicle. So cavitation cannot be avoided but ***needs to be managed***.
- ***Computational modeling*** plays a key role in design of SSC LRE propellant test systems helping mitigate safety and control issues.
- Little to no data for cavitating cryogenic propellants to ***validate two-phase*** CFD codes.
- ***Non-intrusive diagnostics*** have the potential to study cavitation at a fundamental level providing ***first-of-a-kind measurements/insights***.

Proposed SSC-focused Research Project





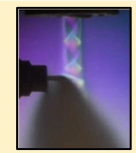
- **Build** LRE propellant test facility: Cryogenic propellant handling needs controlled conditions and safety considerations available at select universities. Setup design in collaboration with SSC will develop capabilities with long-term potential.
- **Measure** cavitation length for LOx/LNG and correlate to cavitation number ($\mathrm{CN} = (P_1 - P_{vap})/(P_1 - P_2)$)
- **Validate** two-phase SSC CFD codes
- **Study** bubble formation and collapse using optical diagnostics:
  - PIV – Flowfield and local velocity/pressure
  - PDPA – Bubble size and growth
  - Schlieren – Cavitation length

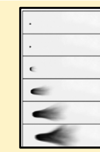
Dorney, D. J. (2021). *NASA Technical Bulletin No. 21-01*

EPL Research Capabilities

Multiphase Flow Experiments

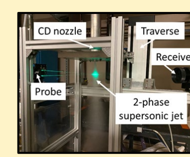
- Droplets in supersonic gas flow
- Melt-layer combustion in hybrid rocket combustor
- Shock wave induced droplet breakup





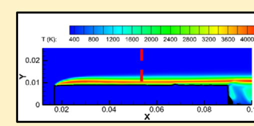
Diagnostics & Imaging

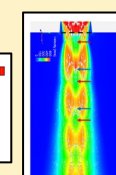
- Phase Doppler Particle Anemometry
- High-speed schlieren, high-speed imaging
- Particle Image Velocimetry
- Chemiluminescence & Laser-induced fluorescence



Numerical Simulations

- Two-phase flow modeling in Ansys Fluent
- Volume-Of-Fluid (VOF) method for multi-phase flows





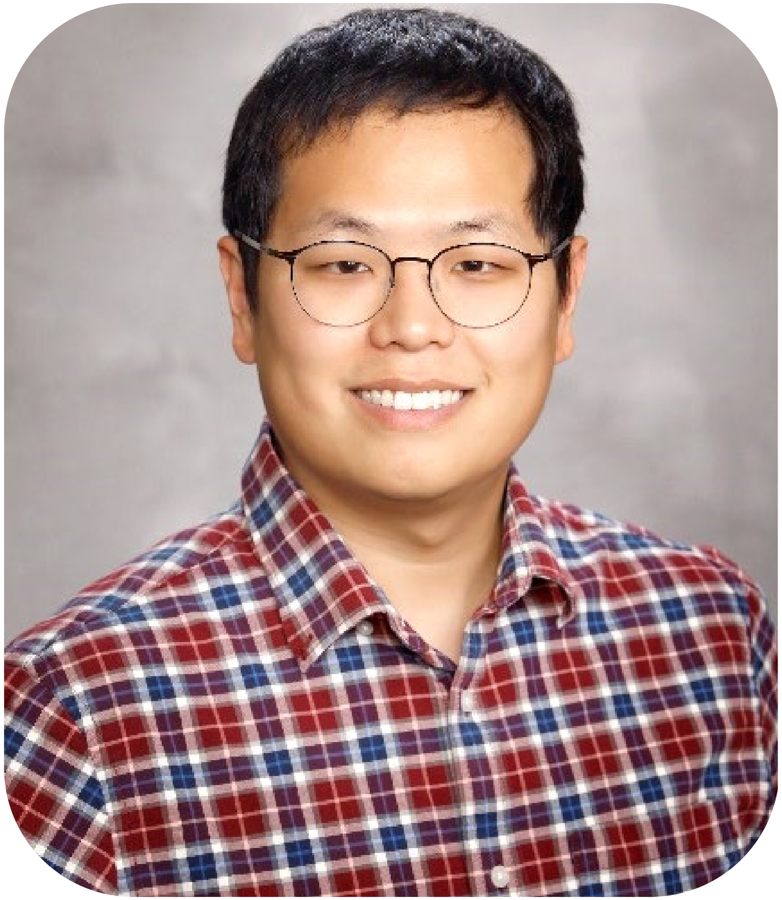
Energy and Propulsion Laboratory (EPL)

Dr. Shyam Menon

LSU College of Engineering Department of Mechanical & Industrial Engineering

Advanced Rocket Propulsion Test Instrumentation

Testing instrumentation and techniques for advanced rocket propulsion system



Dr. Seokwon (Alex) Cho

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Seokwon (Alex) Cho is an assistant professor of Aerospace Engineering at Mississippi State University. He received his B.S. in Mechanical and Aerospace Engineering at Seoul National University, where he also finished his Ph.D. in 2018. In 2019, he joined University of Minnesota–Twin Cities as a postdoctoral associate and lecturer, followed by two years of service as a postdoctoral appointee at Sandia National Laboratories in Livermore, CA.

His expertise mainly focuses on experimental research and testing advanced propulsion systems. AThEnA Laboratory is competent with testing system setup, refined data acquisition & measurement, and data post-processing and analysis. The laboratory has extensively been involved in analyzing pressure, temperature, and other heat-related data in a combustion environment. AThEnA's current research focuses on the following: developing high-frequency telemetry data acquisition systems for high-speed electrical motors, developing MEMS-based heat-flux sensors for advanced thermal and propulsion systems, combustion behavior of alternative fuel (e.g., high-ethanol content) using experiments and CFD large-eddy simulations (LES) in engine application.

Test instrumentation and techniques for advanced rocket propulsion system

SSC research/development priority | ***Advanced Rocket Propulsion Test Instrumentation***

Motivation

vehicle

Data acquisition w/ embedded system

e.g., AD boards + serial comm.
NI PXI or cRIO system
*depends on requirements

Pressure
Temperature
Heat-flux
Strain gauge
Near-field acoustics
Etc.

Flexibility in choice of measure
Voltage, amperage measurements
Signal amplifications
Pertinent post-processing

Time domain synchronization

e.g., IRIG-B

NIST standard
e.g., WWVB 60kHz IRIG-H

Data monitoring system/logger

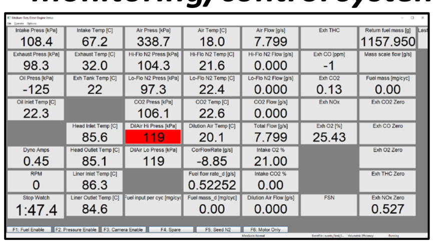
Time-synchronized data
Required post-processing (e.g., FFT, PDF)
*depends on SSC's format requirement

Communication via protocol with other nodes

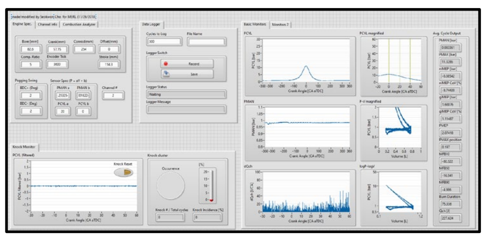
Serial communication
(e.g., RS232/485, CAN)
*depends on SSC's current application

Research capabilities

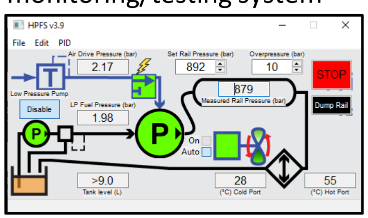
- ***Development of data acquisition, post-processing and monitoring/control system***



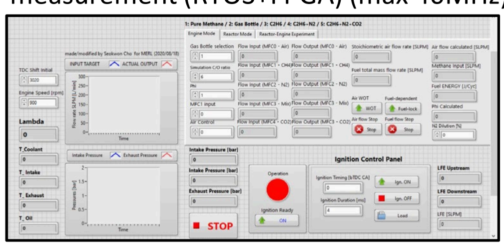
Python-based engine monitoring/testing system



NI PXI-based high-speed data (P, T) measurement (RTOS+FPGA) (max 40MHz)

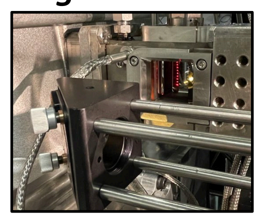


High-pressure (2000 bar) fuel control system

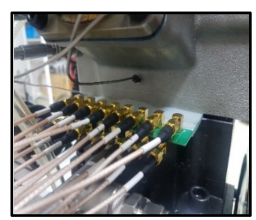


NI cRIO-based high-speed controller for combustion testing (RTOS+FPGA)

- ***Combustion diagnostics***

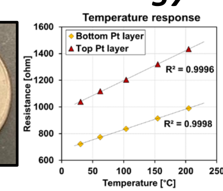


Mid-IR laser diagnostics For CH2O measurement

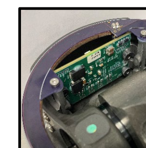


High-speed FID for flame shape characterization

- ***New micro-heat-flux sensor technology***

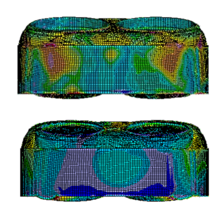


MEMS-based sandwich structure heat-flux sensor

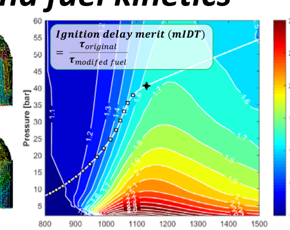


High-speed engine telemetry

- ***CFD LES and fuel kinetics***



ICE wall heat flux simultaion



Fuel ignition delay characterization

ATh**E**nA **A**dvanced **T**hermal and **E**nergy – **A**erospace Research Laboratory

Dr. Seokwon (Alex) Cho

MISSISSIPPI STATE UNIVERSITY™
JAMES WORTH BAGLEY COLLEGE OF ENGINEERING

Advanced Rocket Propulsion Test Instrumentation

Using phosphors like EuD4TEA to measure impacts, radiation, fluence, and surface temperatures for space applications

Dr. William A. (Andy) Hollerman

University of Louisiana at Lafayette
Professor, Department of Physics
Associate Director, Louisiana Accelerator Center
Radiation Safety Officer
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Dr. William Andrew (Andy) Hollerman is currently a Professor of Physics, the Director of the Louisiana Accelerator Center (LAC), and the Radiation Safety Officer at the University of Louisiana at Lafayette. He completed a Ph.D. in Applied Physics, with concentration in Materials Science, from Alabama A&M University in May 1996. He has earned Masters degrees in Physics (experimental atomic effects) from Western Michigan University in 1985 and Physics (radiation effects) from Purdue University in 1986. Dr. Hollerman also completed a group-major Bachelors degree in Mathematics and Physics from St. Joseph's College in Indiana.

Since his arrival in 1998, Andy has taught general physics and astronomy courses to hundreds of students. He is keenly interested in space physics and has active research projects with the Louisiana Space Grant Consortium (LaSPACE), NASA, and the Department of Defense. Dr. Hollerman holds a patent for non-burning phosphor-based tracer ammunition. Since 1989, Dr. Hollerman has published many articles in space physics, fluorescence, triboluminescence, phosphor thermometry, radiation physics, applied physics and engineering, and environmental technology in journals such as the IEEE Transactions on Nuclear Science, Nuclear Instruments and Methods in Physics Research, Journal of Luminescence, Journal of Materials Research, and the Journal of Nuclear Materials. He has given presentations on a variety of scientific and technical topics to hundreds of participants.

Using phosphors like EuD_4TEA to measure impacts, radiation, fluence, and surface temperatures for space applications

Research Topic: Advanced Rocket Propulsion Test Instrumentation

Dr. William A. Hollerman, UL Lafayette; Mr. Noah Bergeron, GlowSens; John Miller & Dr. Stephen Allison, EMCO

Background

- A phosphor is a solid material that emits luminescence not caused by incandescence.
- Phosphors have been proposed for use as smart sensors to detect structural damage, measure incident radiation fluence, and monitor surface temperature.
- For fifteen years, we have been investigating triboluminescence from phosphors like europium (III) tetrakis dibenzoylmethide triethylammonium (EuD_4TEA), which is bright enough to be seen in daylight.
- Since the 1950's, it has been known that the emission yield varies as a function of proton fluence.
- Measuring temperature using luminescence, or phosphor thermometry, has documented application in aerospace surface temperature measurements.
- Since the 1980's, research and development was completed into various high temperature, non-contact applications.
- The field has expanded to also include the use of phosphors in gas and liquid flows for simultaneous thermometry and velocimetry.

Approach

- Perform proof-of-concept tests to determine if impacts, radiation fluence, and temperature can be measured for components in rocket test stands and related equipment for NASA applications.
- Use experience gained during UL Lafayette Cajun Advanced Picosatellite Experiment (CAPE) and related programs.

Important Results

Triboluminescence:

- EuD_4TEA emits very bright triboluminescence that is 206% of the yield for ZnS:Mn.
- Triboluminescent emission has been observed from impact speeds of ~1 m/s to 6 km/s.

Radiation Fluence:

- The 3 MeV half brightness fluence value for EuD_4TEA was found to be about $(2.8 \pm 0.19) \times 10^{10}$ mm^{-2}, with the equivalent ZnS:Mn value being 10^3 times more.
- Tribble noted that the 1 MeV proton fluence for a large solar event at one astronomical unit from the sun is less than about 10^{11} mm^{-2}.

Phosphor Thermometry:

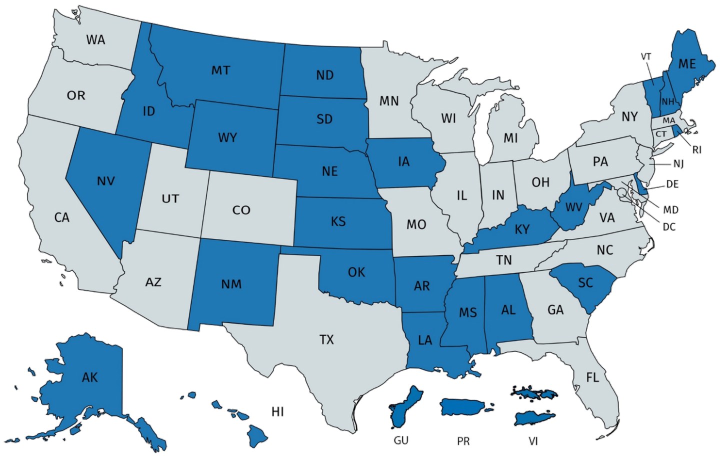
- Experience has shown that non-contact surface temperatures can be measured from less than 77 to 2000 K using phosphor thermometry.
- Potential exists to measure temperature of rocket exhaust plumes using phosphor thermometry.

Key Partners

- UL Lafayette Department of Physics
- GlowSens
- EMCO

Topic Area 3

Autonomous Operations Capability for Ground and Space Applications



NASA EPSCoR Research for SSC
January 27, 2023

Autonomous Operations Capability for Ground and Space Applications

Autonomous Planetary Construction Using ISRU-based Robotic Large-scale 3D Printing

Dr. Ali Kazemian

Louisiana State University
Bert S Turner Department of Construction Management
Division of Electrical & Computer Engineering (Adjunct)
rəcast Laboratory
kazemian1@lsu.edu; (225) 578-3798

Ali Kazemian is an Assistant Professor of Construction Management at LSU, also holding an adjunct position in the division of Electrical and Computer Engineering. He is the director of the LSU rəcast Lab which is focused on various aspects of robotic construction. His current research projects are focused on the process automation, quality control, and innovative printing materials for construction 3D printing (C3DP). In addition to the terrestrial applications of C3DP, he is also researching extraterrestrial C3DP for Lunar and Martian construction, with support from Louisiana Space Grant Consortium (LaSPACE). Before joining LSU, Dr. Kazemian worked as a senior R&D engineer for 3 years at Contour Crafting Corporation – a well-known robotic construction company in California. He earned a PhD degree in Civil Engineering (2018) and a Master's degree in Computer Science from USC. His research efforts so far have resulted in publication of a book, 3 book chapters, and 16 journal papers in the areas of robotic construction and advanced construction materials.

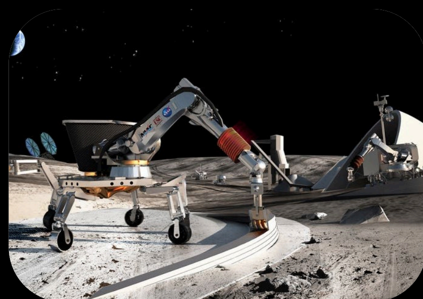
Autonomous Planetary Construction Using ISRU-based Robotic Large-scale 3D Printing

Ali Kazemian (Louisiana State University)

Introduction

NASA SSC Research Area:
Autonomous Operations Capability for Ground and Space Applications

Research Goal:
Enable fully-automated construction on the planetary surfaces using in-situ resources and robotic construction technologies



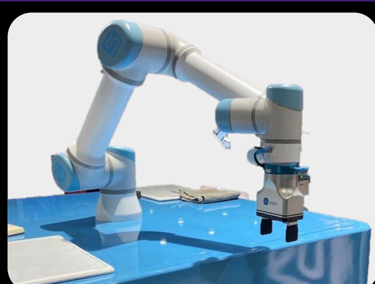
Proposed SSC/LSU Research

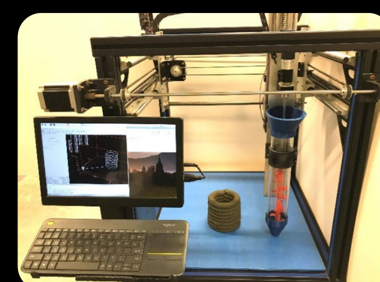
Proposed Research:
Automated In-line Quality Control Systems to Enable Fully Autonomous Planetary Robotic Construction

Main Objective:
Developing and studying automated quality control techniques using embedded sensors/computing (e.g. LiDAR and Computer Vision) to improve the reliability and robustness of robotic planetary construction using 3D printing and in-situ resources

Real-time Shape Fidelity Measurements ← **3D Point Cloud Data** ←

Research Capabilities

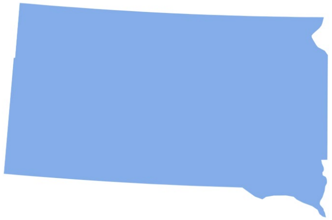




(Top) Various construction robots at Kazemian's lab at LSU
(Bottom) 3D Printed specimens using Lunar and Martian regolith simulants

racast LSU

LSU Bert S. Turner Department of Construction Management



Autonomous Operations Capability for Ground and Space Applications

Autonomous Robotic Walking Machines for Surface Exploration & ISRU

Dr. Pierre Marc Larochelle, P.E.

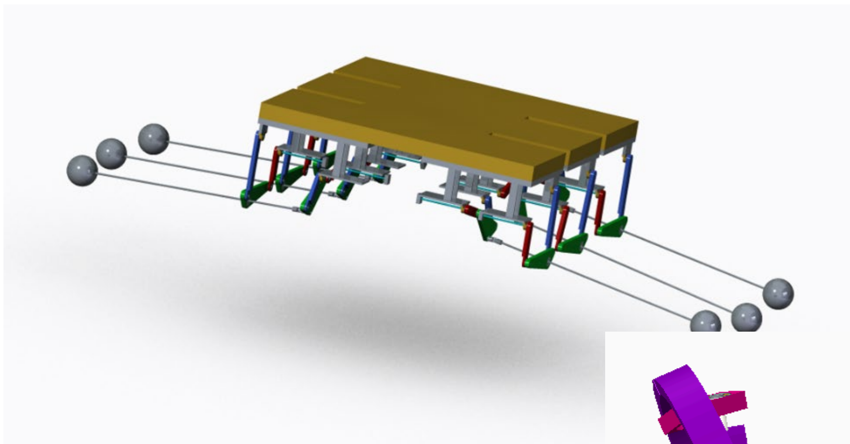
South Dakota School of Mines & Technology
Department of Mechanical Engineering
Robotics and Computational Kinematics Innovation Engineering (ROCKIN) Laboratory
Pierre.Larochelle@sdsmt.edu; (605) 394-2401

Pierre Larochelle serves as Department Head and Professor of Mechanical Engineering at the South Dakota School of Mines & Technology. His research focuses on the design of complex robotic mechanical systems and enabling creativity and innovation in design. He has over 100 publications, holds three US patents, and serves as a consultant on robotics, automation, machine design, creativity & innovation, and computer-aided design. In 2012, at NASA's request, he created a 3-day short course on Creativity & Innovation. This course has been very well received, and he has taught it exclusively more than 30 times at NASA's various centers and laboratories across the nation to more than 600 of NASA's scientists and engineers. He currently serves as the Chair of the U.S. Committee on the Theory of Mechanisms & Machine Science and represents the U.S. in the International Federation for the Promotion of Mechanism & Machine Science (IFToMM) (2016-22). He currently serves as a founding Associate Editor for the ASME Journal of Autonomous Vehicles and Systems. He has served as Chair of the ASME Design Engineering Division (2018-2019) and the ASME Mechanisms & Robotics Committee (2010-2014), and as an Associate Editor for the ASME Journal of Mechanisms & Robotics (2013-19), the ASME Journal of Mechanical Design (2005-11), and for Mechanics Based Design of Structures & Machines (2006-13). He is a Fellow of the American Society of Mechanical Engineers (ASME), a Senior Member of IEEE, and a member of Tau Beta Pi, Pi Tau Sigma, ASEE, and the Order of the Engineer.

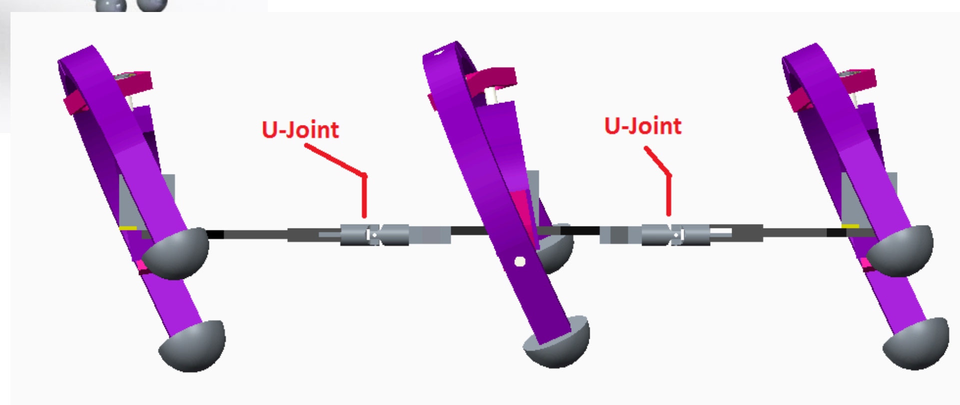
SOUTH
DAKOTA
MINES

ROBOTIC WALKING MACHINES FOR SURFACE EXPLORATION & ISRU

SphereWalker and SCUD Walker



For more information and videos click here.



- Autonomous or Semi-Autonomous Modalities
- Bio-inspired hexapods that are energy efficient and can carry large payloads

P. Larochelle

CURIOUS
SMART
TENACIOUS

NASA EPSCoR Research for SSC
January 27, 2023

Autonomous Operations Capability for Ground and Space Applications

Physics-based simulation of off-road ground robots

Dr. Christopher T. Goodin

Mississippi State University
Center for Advanced Vehicular Systems (CAVS)
cgoodin@cavs.msstate.edu; (615) 336-1249

Chris Goodin is a research faculty at the Center for Advanced Vehicular Systems (CAVS) at MSU. His research expertise is in off-road navigation by autonomous ground vehicles (AGV) and modeling and simulation tools for developing and testing off-road autonomy. Dr. Goodin is the lead developer of the MSU Autonomous Vehicle Simulator (MAVS), and simulation library for AGV with hundreds of government and academic users worldwide, most notably at the US DoD. Dr. Goodin is also the lead developer of the NATURE autonomy stack, an open source autonomy stack for off-road navigation being used by researchers in the NATO Applied Vehicle Technology group to study off-road vehicles.

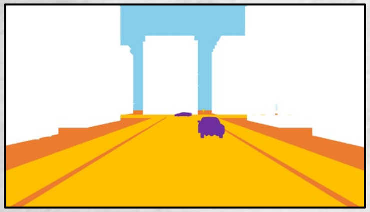
The MSU Autonomous Vehicle Simulator (MAVS)

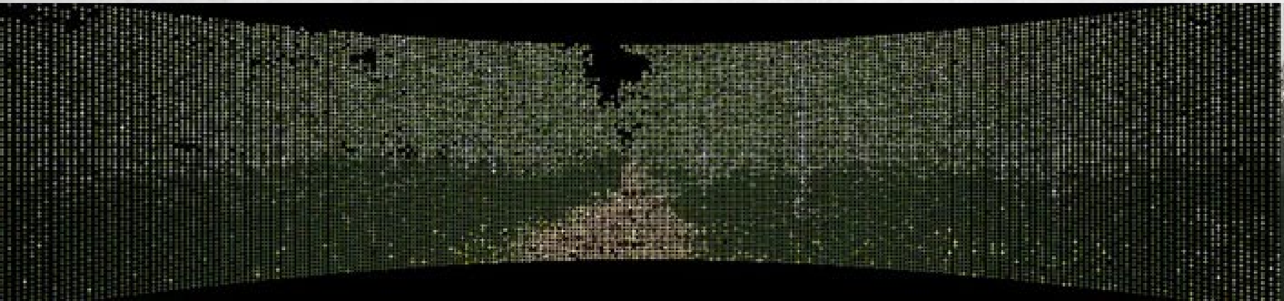
Motivation:

- Autonomous systems require millions of hours of experimentation to train, test, and evaluate with confidence.
- Game-engine simulators are inadequate for off-road applications

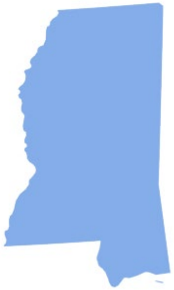
Our Research:

- Sensor-environment physics
  - lidar/weather interaction
  - sensor performance in dense veg
  - sensor soiling
- Integrated physical/simulated test methods
- Tire-soil interaction simulation
- Autonomy & machine learning education
- Swarm / teaming simulations
- Perception in off-road terrain





NASA EPSCoR Research for SSC
January 27, 2023



Autonomous Operations Capability for Ground and Space Applications

Incremental Learning with Knowledge Distillation for Autonomous Rover Terrain Characterization

Dr. Jingdao Chen

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Department of Computer Science and Engineering
chenjingdao@cse.msstate.edu; (662) 325-7514

Jingdao Chen is an Assistant Professor in Computer Science and Engineering at Mississippi State University. He received his Bachelor's degree in Electrical Engineering from Washington University in St. Louis in 2015, his Master's degree in Computer Science from Georgia Institute of Technology in 2019, and his Ph.D. in Robotics from Georgia Institute of Technology in 2021. His research interests include robotics, machine learning, artificial intelligence and computer vision. His research specialization is in deep learning-based perception of unstructured environments for robotics applications. Dr. Chen has previously collaborated with NASA JPL on a Data Science Working Group project titled CLOVER: Contrastive Learning for Onboard Vision-Enabled Robotics. The project developed a contrastive learning scheme for improving performance on downstream vision tasks for Mars rovers in a data-efficient manner. Other research capabilities include algorithms for autonomous path planning, image processing, scene understanding and mobile computing.

Incremental Learning with Knowledge Distillation for Autonomous Rover Terrain Characterization

Autonomous operations capability for ground and space applications

Problems

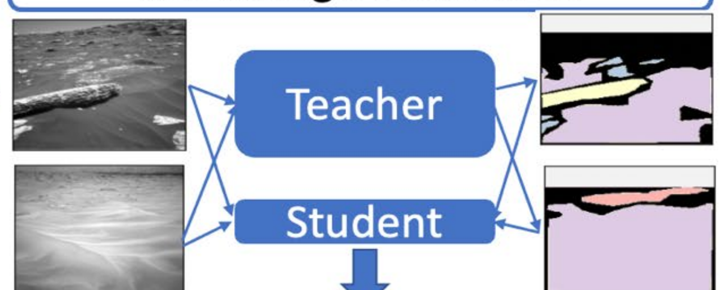
- Space rovers are driven autonomously at ~7% with an average drive distance of only ~30m
- Space-qualified hardware have significant computing limitations
- Planetary terrain is potentially hazardous and varying from site-to-site

Approach

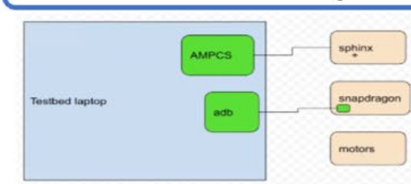
- Incremental contrastive learning to enable continuous updating of a terrain characterization model with unannotated data
- Knowledge distillation and mobile optimization to facilitate deployment of deep learning models on spaceflight computers

Incremental Contrastive Learning

Knowledge Distillation



Mobile Optimization



Dr. Jingdao Chen

MISSISSIPPI STATE UNIVERSITY™
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Autonomous Operations Capability for Ground and Space Applications

Enabling Cislunar Spacecraft Autonomy Using Learning-Based Algorithms and Convex Optimization

Dr. Ehsan Taheri

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Department of Aerospace Engineering
Aero-Astro Computational & Experimental (ACE) Laboratory
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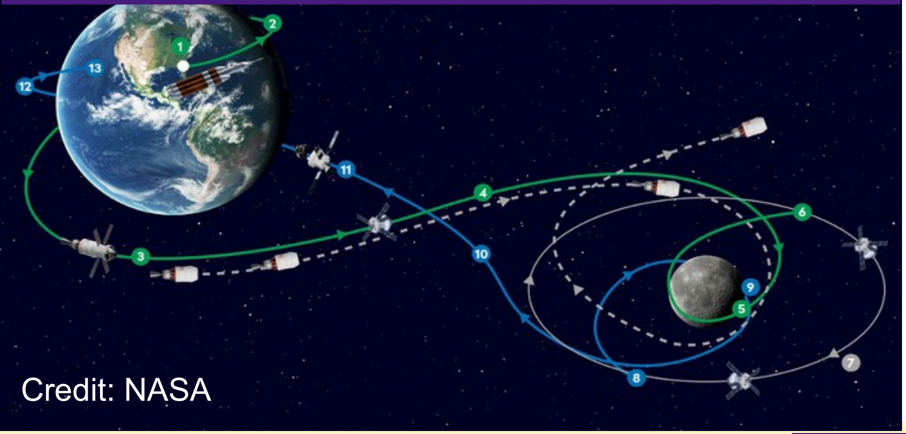
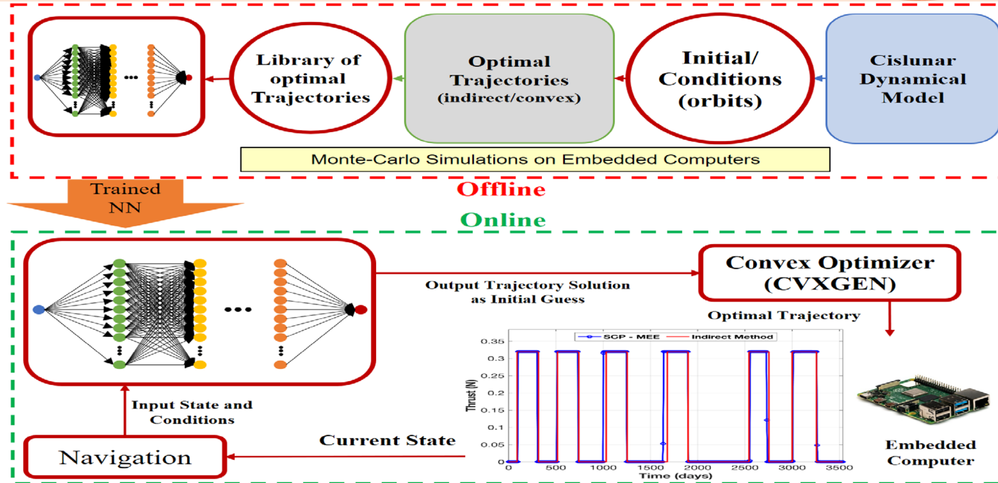
Ehsan Taheri is an Assistant Professor of Aerospace Engineering at Auburn University. He's the director of the Aero-Astro Computational and Experimental (ACE) Lab. His research expertise is at the intersection of optimal control theory, control engineering, and space and atmospheric flights. Since 2019, Dr. Taheri's primary area of activity has been on the development of rapid numerical methods for generation of spacecraft optimal impulsive and low-thrust trajectories. In addition, his research group have deployed motion-planning algorithms on embedded systems for trajectory optimization of multi-rotor unmanned aerial vehicles. The ACE Lab is equipped with an OptiTrack motion-capture system and multitude of multi-rotor vehicles and provides an experimental testbed for testing the developed guidance and motion-planning algorithms on low-cost, custom-built quad- and multi-rotor platforms.

Enabling Spacecraft Autonomy Using Enhanced Learning-based algorithms and Convex Optimization

Autonomous guidance for Cislunar & Artemis





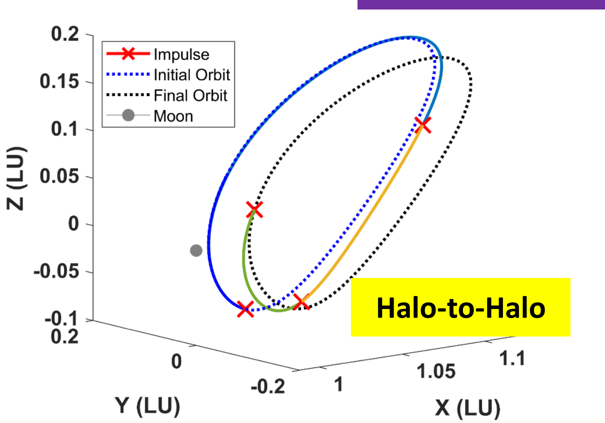
Our Research

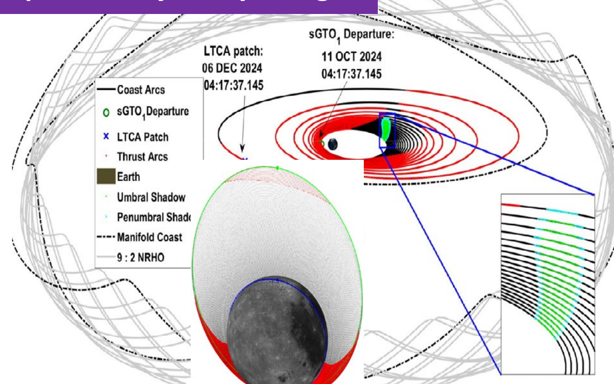
Tools
- Optimal control theory
- Nonlinear systems theory
- Convex optimization
- Learning-based algorithms

Applications
- Low-thrust transfer maneuvers
- Cis-lunar & Artemis missions
- Close proximity maneuvers
- Transfer between Halo and other orbits

Outcomes
- Real-time optimal decision making enabling autonomous systems for Artemis capabilities
- Fuel- time-optimality guarantees
- Collision/obstacle avoidance

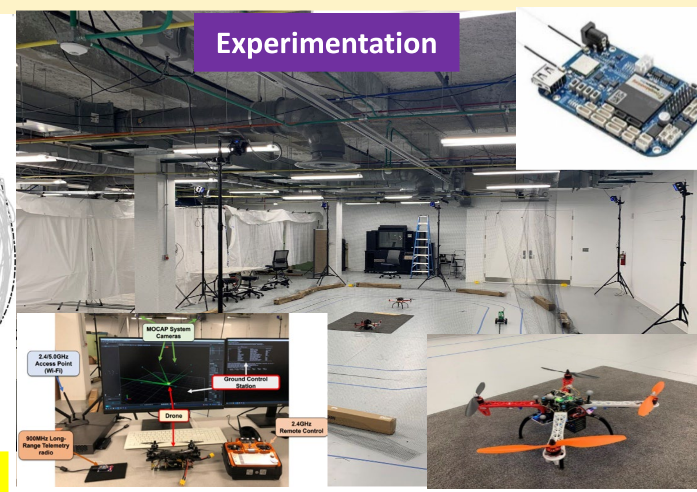
Cislunar rapid & optimal Trajectory Design





GTO-to-NRHO

Experimentation



Aero-Astro Computational & Experimental Lab

Dr. Ehsan Taheri

Samuel Ginn College of Engineering
Department of Aerospace Engineering

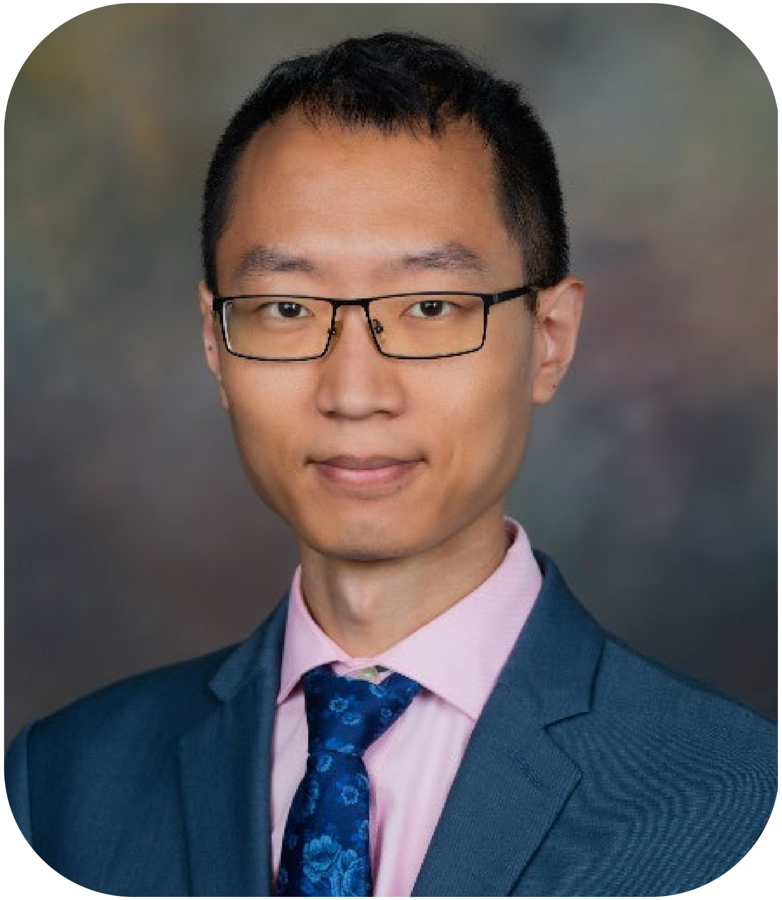
Autonomous Operations Capability for Ground and Space Applications

Cloud-Assisted Autonomy for Artemis Missions

Dr. Nan Li

Auburn University
Department of Aerospace Engineering
Intelligent Systems and Robotics Lab
nzl0058@auburn.edu; (734) 548-2138

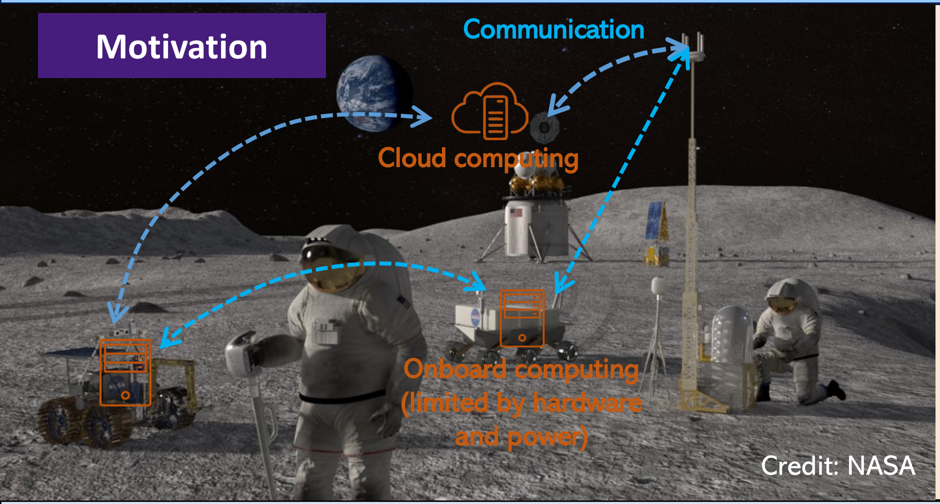
Nan Li is an Assistant Professor of Aerospace Engineering at Auburn University. His expertise and interests lie at the intersection of systems theory, optimization, and artificial intelligence. Since joining the Department of Aerospace Engineering at Auburn University, his research has focused on the theory and methods for safe autonomy, multi-agent systems, connected cyber-physical systems, and their applications for advanced mobility and space exploration. He is particularly interested in investigating new decision/control approaches and autonomous systems enabled by emerging computational paradigms including cloud computing and distributed/edge computing.

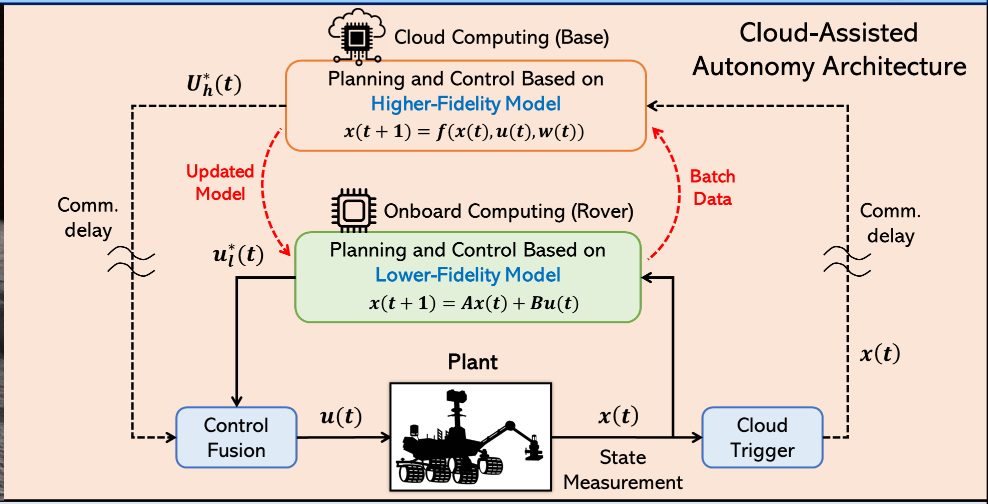


Cloud-Assisted Autonomy For Artemis Missions

SSC Topic: Autonomous Operations Capability for Ground and Space Applications

Motivation





Our Research

Tools

- Optimal control
- Real-time optimization
- Time-delay analysis
- Estimation & learning

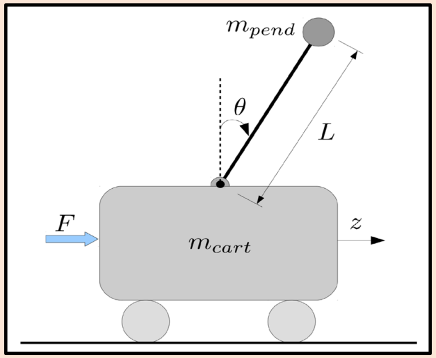
Applications

- Path planning & following with obstacle avoidance
- Safe online learning
- Multi-agent coordinated control

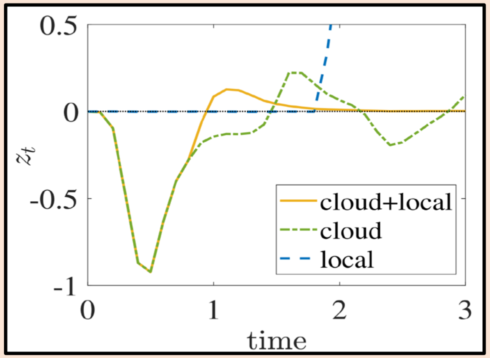
Outcomes

- Cloud-assisted real-time planning & control framework
- Safety guarantee (obstacle avoidance under uncertainty)
- Online adaptation to uncertainty & replanning
- Multi-agent coordination

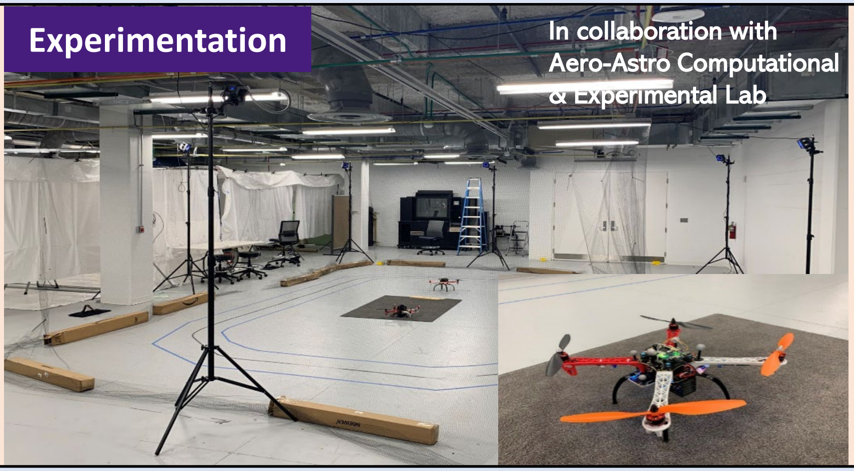
Preliminaries



Cloud-assisted control achieves superior performance



Experimentation



Auburn Intelligent Systems and Robotics Lab

Dr. Nan Li

Samuel Ginn College of Engineering
Department of Aerospace Engineering

NASA EPSCoR Research for SSC
January 27, 2023

Autonomous Operations Capability for Ground and Space Applications

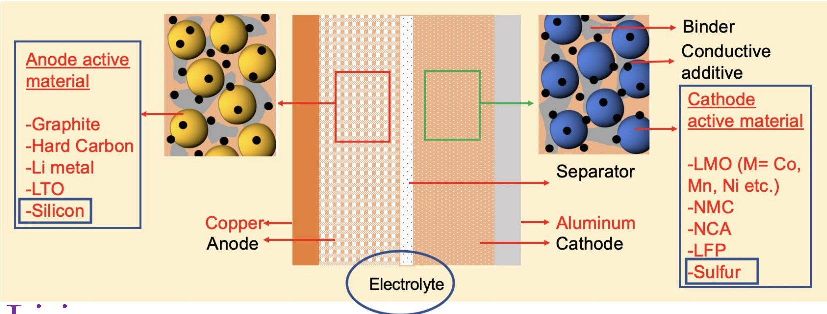
Energy storage systems for operation in extended temperature range (-60 to +60 °C).

Dr. Ramakrishna Podila

Clemson University
Department of Physics & Astronomy
Laboratory of Nano-biophysics
rpodila@g.clemson.edu; (864) 656-4447

Rama Podila is an Associate Professor of Physics and Astronomy at Clemson University. His lab aims to seamlessly integrate the principles of condensed matter physics, optical spectroscopy, and physiological chemistry to understand physics at the nanoscale and nano-bio interfaces. Our research efforts may be categorized into three broad themes: 1) Energy conversion and storage, 2) Nanotoxicity and nanomedicine, and 3) Quantum biophysics. In terms of energy storage, Nano-bio lab made significant strides in defect-engineered graphene supercapacitors, novel current collectors for Li-ion batteries, nanostructured Si anodes and sulfurized polymer cathodes for Li-S batteries. His work thus far has led to >70 peer-reviewed articles (>6000 citations with a H-index: 45) in high-impact journals including Nature, 3 patents, and several invited talks. His group's research has been supported through funding from NIH/NIEHS, NASA, and NSF.

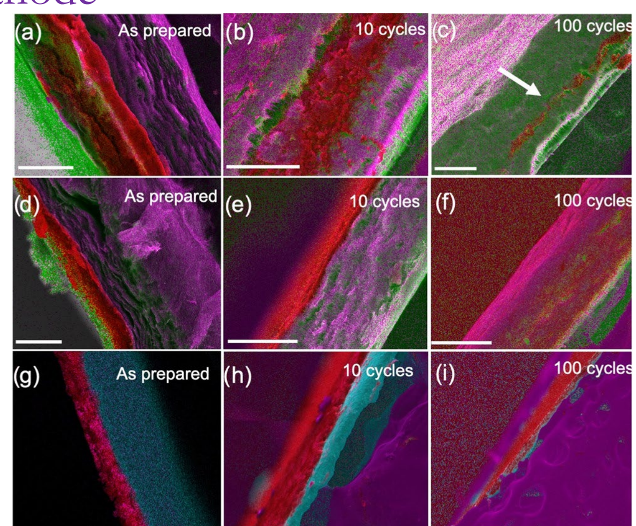
Energy storage systems for operation in a wide temperature range -60 to +60 ^{o}C



Li-ion

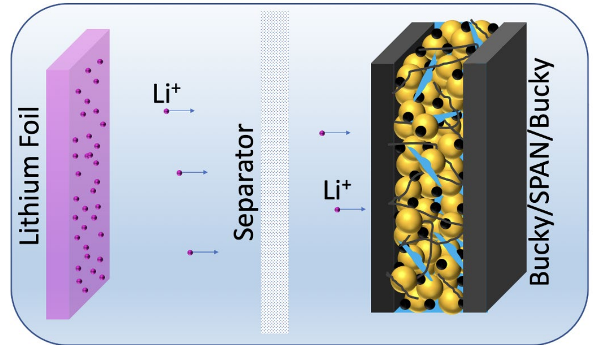
ACS Omega 2018, 3, 4, 4502

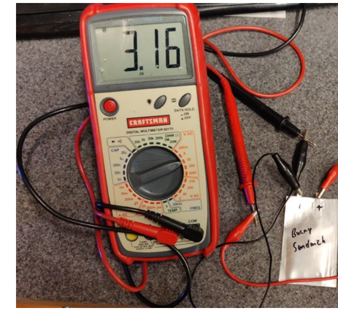
Si anode



ACS Appl. Mater. Interfaces 2020, 12, 31, 34763

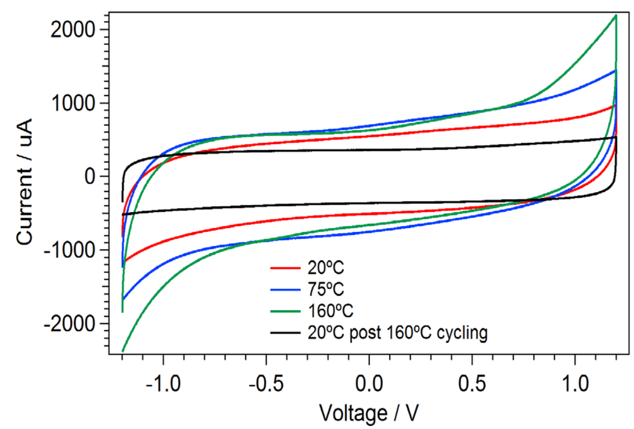
Li-S capacitor





ACS Appl. Nano Mater. 2021, 4, 1, 53–60

Graphene foam capacitor



Advanced Materials 28 (33), 7185-7192

1) Develop hybrid energy storage systems combining Li-ion capacitors and batteries capable of operation in a wide temperature range
2) Novel solutions for pack-level thermal management to avoid hotspots, thermal runaway
3) Battery metrics, performance, and failure modeling

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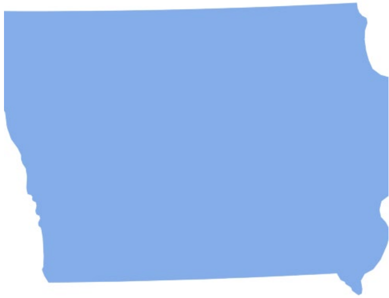

Autonomous Operations Capability for Ground and Space Applications

Self-Organizing Distributed Antenna Arrays for Reach-back and Sensing

Professor Soura Dasgupta

F. Wendell Miller Distinguished Professor
Department of Electrical and Computer Engineering
University of Iowa
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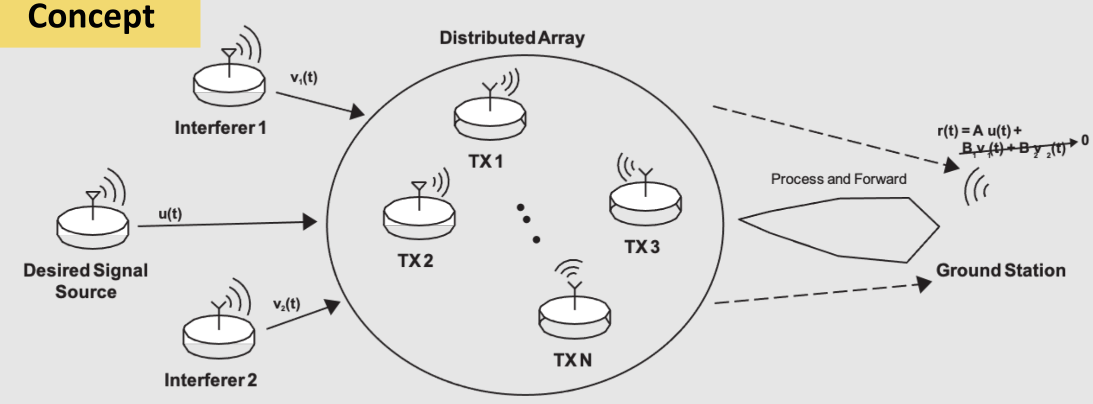
Soura Dasgupta is an F. Wendell Miller Distinguished Professor in the Department of Electrical and Computer Engineering at the University of Iowa. His research interests include distributed sensing, control, communication, and signal processing. He was elevated to the rank of a Fellow of the IEEE in 1998, is a past Presidential Faculty Fellow (precursor to PECASE), and past Associate Editor of IEEE Transactions on Automatic Control and IEEE Transactions on Circuits and Systems II. His research as been funded by NSF, NIH, ONR, ARO and DARPA. His collaborator Professor Raghuraman Mudumbai and he have developed fundamental theory and performed experimental demonstrations that will serve as a stepping-stone for the proposed research.

Self-Organizing Distributed Antenna Arrays for Reach-back and Sensing

Stennis Space Center Area of Interest: **Autonomous Operations Capability for Ground and Space Applications**

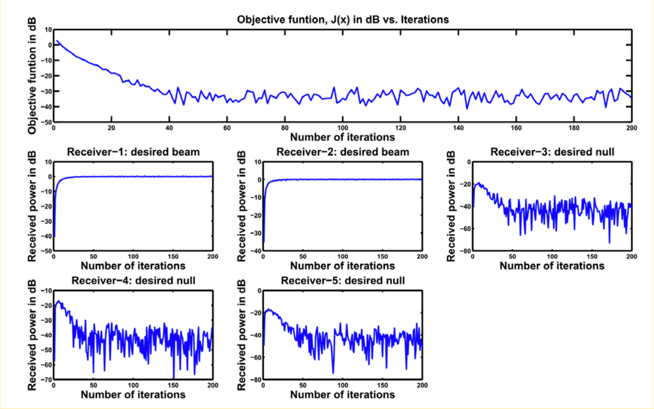
Concept



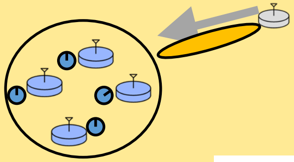
- Multiple wireless transceivers with small antennas *self-organize* into a virtual antenna array with large synthetic aperture
- Satellites, autonomous ground and aerial vehicles
- Array nodes always transmit *collectively*
- Messages to array always *collectively addressed*
- Individual nodes effectively invisible
- Nodes can come and go, array adapts automatically
- Novel and radical, but entirely feasible
  - Key building blocks exist
- PIs have long experience, relevant expertise
  - Participants in DARPA PReW and ReACT projects

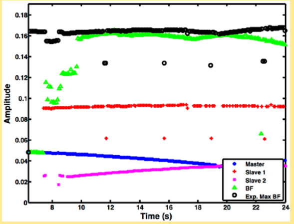
Our Research

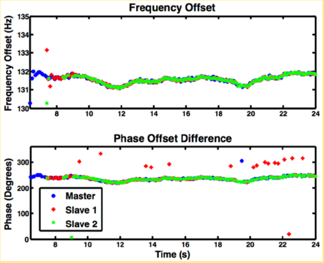
Analytical/Computer Simulation



Experimental Demos







Tools

- Precision synchronization and ranging from carrier phase
- Multi-agent control
- Nonlinear Stability

Applications

- Sensing and Reachback
- Range increase through constructive interference
- Interference cancellation using nullforming

Outcomes

- **First-ever experimental demonstrations of retrodirective beamforming and nullforming from a fully-wireless distributed array**
- **Contributed to successful demos of Electronic Warfare applications for DARPA PrEW and ReACT projects**

Prof. Soura Dasgupta, Prof. Raghu Mudumbai

THE UNIVERSITY OF IOWA

Autonomous Operations Capability for Ground and Space Applications

Modeling, Learning, and Control for Autonomy and Human-Robot Collaboration Systems

Dr. Yue Wang

Clemson University
Department of Mechanical Engineering
Interdisciplinary & Intelligent Research (I2R) Laboratory
yue6@clemson.edu; (864) 656-5632

Dr. Yue Wang is the Warren H. Owen – Duke Energy Professor of Engineering and the Director of the Interdisciplinary & Intelligent Research (I2R) laboratory at Clemson University. Her research interests include human-robot interaction, multi-robot systems, and cyber-physical systems. Dr. Wang received both AFOSR YIP award and NSF CAREER award. Her research has been supported by NSF, AFOSR, ARC, ARO, NASA EPSCoR, ONR, AFRL, and Clemson University. Her work has resulted in over 80 journal publications, peer-reviewed conference papers, and books, which are cited 2,097 times (Google scholar) with an h-index of 23. Dr. Wang is a senior member of IEEE, and a member of ASME and AIAA and serves as Associate Editor on several journals and conference proceedings. Her work has been featured in NSF Science360, ASEE First Bell, State News, SC EPSCoR/IDeA Research Focus, and Clemson University.

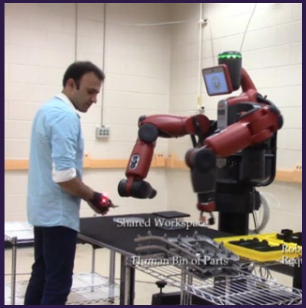
Modeling, Learning, and Control for Autonomy and Human-Robot Collaboration Systems (Autonomous Operations Capability for Ground and Space Applications)

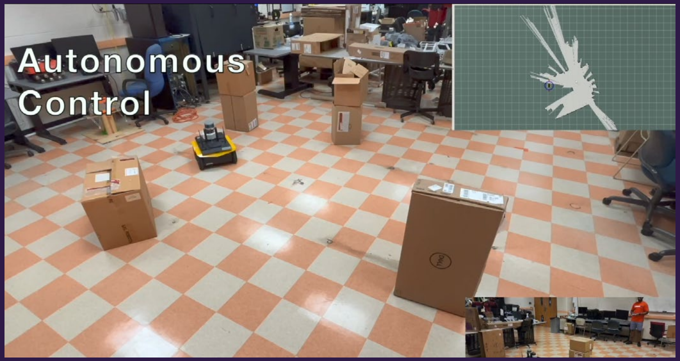
CLEMSON MECHANICAL ENGINEERIGN

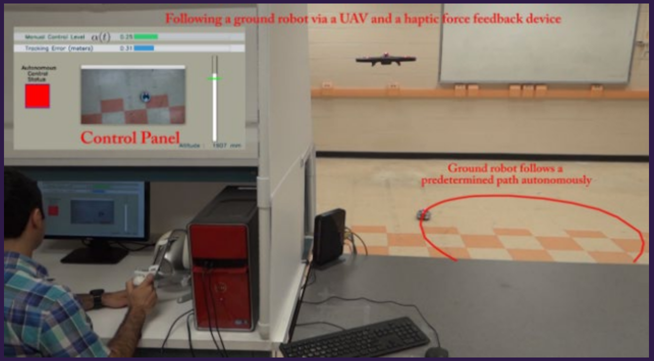
Dr. Yue Wang is the Warren H. Owen – Duke Energy Professor of Mechanical Engineering and the Director of the I2R lab at Clemson University.

Research Overview:

- Computational models for human-robot trust
- Modeling of human risk attitudes in human-robot interaction
- Shared control of mobile robots
- Human-robot collaborative manufacturing
- Symbolic motion planning for multi-robot systems
- Formal verification for autonomous vehicles (AVs)/robots
- Human-aware autonomous driving
- Deep reinforcement learning for robots
- Enhanced situational awareness for Avs
- Distributed multi-agent coverage control







CLEMSON
MECHANICAL ENGINEERING

NASA EPSCoR Research for SSC
January 27, 2023

Autonomous Operations Capability for Ground and Space Applications

Run-Time Trade Space Analysis for Autonomous Surface Operations

Dr. Yu Gu

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West Virginia University, Morgantown, WV 26506-6106
Email: Yu.Gu@mail.wvu.edu
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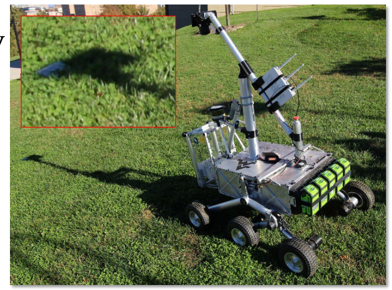
Dr. Yu Gu (Gu) is an Associate Professor in the Department of Mechanical and Aerospace Engineering at West Virginia University (WVU). His main research interest is in improving robots' ability to function in increasingly complex environments and situations. Gu is a three-time NASA Centennial Challenge winner and a NASA NIAC Fellow. He has led the design of autonomous robots from one degree of freedom (DOF) to 55 DOF, from 50mg to 200kg, which were featured in 150 media stories. Gu also led the initiation and development of the WVU Robotics program.

Run-Time Trade Space Analysis for Autonomous Surface Operations

Challenge and Research Goal

- *Challenge*: robots today are not capable of making decision tradeoffs under ever-evolving situations, along with explaining the basis of the decision to human coworkers
- *Goal*: flexible autonomy that can make decisions to balance multiple competing objectives and are understandable by humans



Proposed Approach

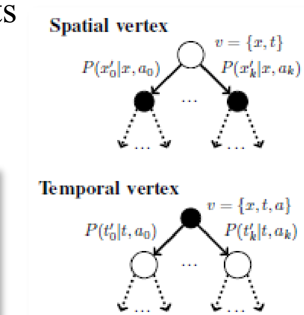
- Develop an autonomy architecture that examines costs, risks, ambiguity, and the level of human inputs in a decision trade space
- Populating the trade space with ensemble-POMDP to represent different experiences and priorities
- Apply Dempster-Shafter theory for matching a set of appropriate policy to a situation
- Represent the decision process to human users

Related Experiences

- Efficient decision-making under uncertainty and ambiguity for supporting Mars Sample Return mission
- Coordination and control of multi -agent systems
- Human-robot interaction
- Custom robot systems design and field experiments

Project Evaluation

- *Case Study*: spatiotemporal energy and risk aware planning for lunar surface operations
- Field experiments in indoor and outdoor planetary analog environments with and without humans in the loop



Yu Gu, (yu.gu@mail.wvu.edu), West Virginia University

NASA EPSCoR Research for SSC
January 27, 2023

Autonomous Operations Capability for Ground and Space Applications

Fast and accurate 3D Extended Object Tracking by Fusing Positive and Negative Information from LiDAR

Dr. Dae Young Lee

Iowa State University
Department of Aerospace Engineering
Cardinal Space Laboratory (CSL)
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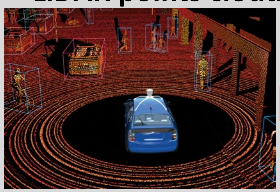
Dr. Dae Young Lee received B.S. and M.S. degrees in mechanical engineering from Pusan National University, Pusan, South Korea. In 2016, he acquired M.S. and Ph.D. degrees in aerospace engineering from the University of Michigan, Ann Arbor, MI, USA. Before his Ph.D., he worked as a Research Engineer at Hyundai Heavy Industry and LS Industrial Systems from 2000 to 2009. He was also a Postdoctoral Researcher at the Center of Space Research of the University of Texas at Austin, TX, USA, from 2016 to 2018, then currently working as an Assistant Professor of aerospace engineering at Iowa State University, Ames, IA, USA. He is also the Director of Cardinal Space Laboratory and researching space missions based on a CubeSat platform, attitude determination and control (ADCS), and entry, descent, and landing (EDL) of a spacecraft. His research interests include nonlinear model predictive control of the car, drone, and spacecraft feet with various constraints and extended tracking of 3D targets using their point clouds.

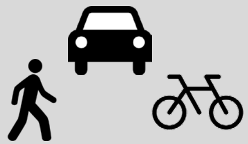
Fast and accurate 3D Extended Object Tracking by Fusing Positive and Negative Information from LiDAR

Motivation

LiDAR points clouds



2D Detect/Identify/Predict



Extension

- LiDAR Points clouds is being exploited to identify various object in 2D.
- However, their 3D extension need to process more information rapidly.

Goal

3D Detect/Identify/Predict

UAV

Drone

Bird

Space debris

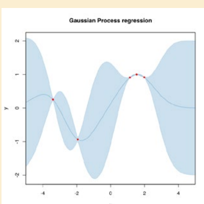
Urban 'air' mobility safety

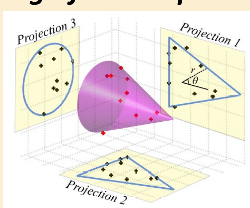
Protective classification (DOD)

Intercept or docking (Space)

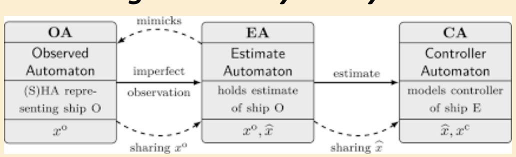
Key concepts

- ***GPR based modeling of 3D shape***





- ***Multi-algorithmic hybrid system***



- ***Positive/Negative information fusing***

200 points

100 points

10 points

Weighting

Dynamics

Our Research

Tools

- Hybrid system theory
- Information fusion (Positive / Negative information)
- Gaussian Process Regression (GPR)

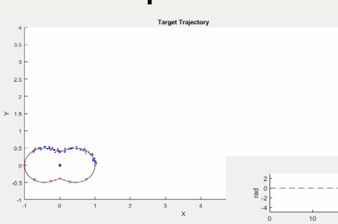
Outcomes

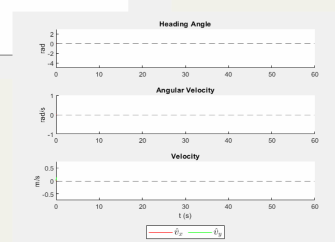
- Multi-algorithm hybrid estimation (EKF/UKF/Etc.)
- Position, velocity, rotational motion, and shape estimation

Applications

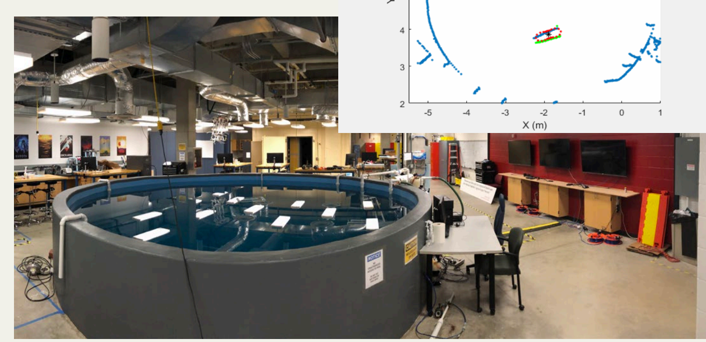
- Self-driving urban air mobility
- UAV/Drone defense
- Space debris removal

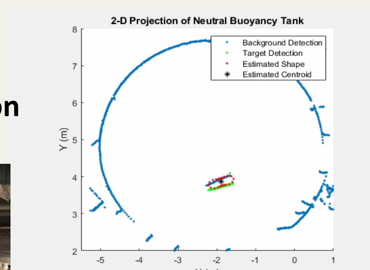
Computer Simulation





Experimental Verification





IOWA STATE UNIVERSITY
College of Engineering

Dr. Dae Young Lee
Aerospace Engineering

CARDINAL SPACE LABORATORY

NASA EPSCoR Research for SSC
January 27, 2023

Autonomous Operations Capability for Ground and Space Applications

Autonomous Fault-Tolerant Operations of Redundant Robots for Space Exploration

Dr. Biyun Xie

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Intelligent Robotic Arms (IRA) Laboratory
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Biyun Xie is an Assistant Professor in the Electrical and Computer Engineering Department at the University of Kentucky. She is the director of the IRA Lab. Her research interests include redundant robots, collaborative robots, and human-robot interaction. Science 2015, Dr. Xie's primary area of activity has been autonomous fault-tolerant operations of redundant robots. Such autonomous systems are intrinsic to missions performed in remote and hazardous environments, such as space exploration, nuclear waste remediation, and disaster rescue. The IRA Lab is home to a seven-degrees-of-freedom Kinova robot arm, which is an ultra-lightweight collaborative robot with a vision system. The testbed can be used to validate the intelligent fault-tolerant motion planning algorithms developed to increase the robustness of the systems.

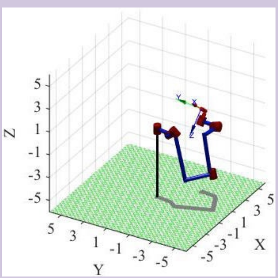
Fault-Tolerant Operations of Redundant Robots for Space Exploration

Motivation

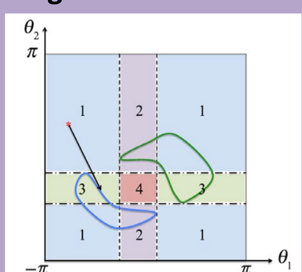
Autonomous Operations Capability for Ground and Space Applications

key Aspects

Kinematic design of optimally fault-tolerant robots



Fault-tolerant motion planning of redundant robots



Our Research

Tools

- Deep Feedforward Networks
- Reinforcement learning
- Genetic algorithm

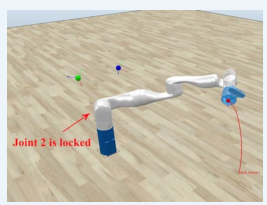
Applications

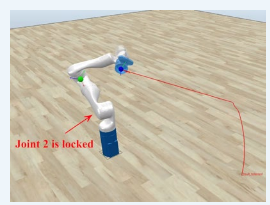
- Space exploration
- Nuclear waste remediation
- Disaster rescue

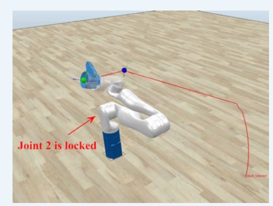
Outcomes

- Increase the robustness
- Realize autonomous fault-tolerant operations

Computer Simulation







Experimentation

Intelligent Robotic Arms Lab

Dr. Biyun Xie

Department of Electrical and Computer Engineering