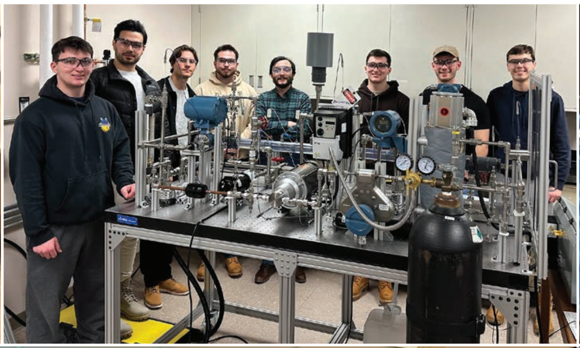
NAVAL ENGINEERING EDUCATION CONSORTIUM PROCEEDINGS 2024

NEEC

Naval Engineering Education Consortium



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About NEEC

We are happy to present the 2024 Naval Engineering Education Consortium (NEEC) Proceedings, highlighting the exceptional depth and breadth of work of our research partnerships. The NEEC program unites students, professors, and Navy scientists and engineers to tackle current and future technical challenges through project-based research, with the aim of attracting and accelerating the development of the next generation of naval engineering talent. In today's landscape of intensifying global technological competition, it is crucial to strengthen America's science and engineering workforce and foster closer collaboration with academic partners to secure an enduring advantage for the U.S. Navy and the nation.

NEEC was established with these goals in mind. Directed by the Naval Sea Systems Command Warfare Centers and implemented by its 10 Divisions across the country, NEEC funds research and development in academic environments, offering students interested in science and engineering careers with the Navy the chance to address real naval challenges alongside university, faculty and Warfare Centers mentors. Colleges and universities, through our Broad Area Agency (BAA) announcement, are invited to submit proposals on technical naval topics; if selected, they receive grants for one year with options for second and third years. Each chosen institution collaborates with a specific Warfare Center Division, guided by its own NEEC director and mentors, to work on a wide range of topics that are important to our current and future U.S. Navy.

Students and faculty have embraced these challenges, and their successes are showcased in this year's NEEC Proceedings. Example projects address pressing issues such as the changing global climate and increased human activity in the Arctic, which require developing new research ideas for expanding naval operations in this region. Artificial Intelligence (AI) projects are critically important, as AI rapidly transforms every industry. Students are exploring AI and Natural Language Processing to control drones, students are using machine learning to support naval antenna research, and developing bio-inspired autonomous vehicles. NEEC projects are determining the effects of exposure of polymer structures to marine environments. Faculty and students are trying to miniaturize sonar systems based on their knowledge of bats. Other NEEC projects are advancing the latest in high-power lasers and fiber optics, to mention just a few.

The Proceedings also highlight the energy and commitment of professors, Warfare Centers scientists and engineers, mentors, NEEC directors, and numerous dedicated personnel who work tirelessly to bring each project to life. We extend our gratitude to all participants, who represent the best talent from the Warfare Centers' workforce and our government, industry, and academic partners, for their efforts in addressing the significant challenges facing the Navy and the nation.

Sally Sutherland-Pietrzak
NEEC Director
Naval Surface and Undersea Warfare Centers

A Message from the Executive Director

Welcome to the annual Proceedings of the Naval Engineering Education Consortium (NEEC). For over a decade, the NEEC has established a track record of recruiting the best and brightest young minds to tackle challenging naval technical problems. This past year was no exception, and the research projects represented in this year's Proceedings are impressive in their own right.

Established by the Naval Sea Systems Command (NAVSEA) to amplify its naval architecture program, and administered by the 10 NAVSEA Warfare Center Divisions, NEEC has three primary objectives:

- Acquire academic research results and products to resolve naval technology challenges.
- Hire college graduates with naval engineering research and development experience into the NAVSEA workforce (bachelor's, master's and doctoral degrees).
- Develop/continue exceptional working relationships with naval engineering colleges, universities, professors, and academics.

Now perhaps more than ever, the collaborative nature of NEEC is helping us grow a resilient defense ecosystem that includes academia, DoD laboratories, national laboratories, commercial industry, and other government departments and agencies. Simply put, in today's challenging environment, we can't meet complex and interconnected challenges alone. Each of the NEEC's project-based research activities are aligned with the future technical capabilities of each participating Warfare Center Division, allowing us to help target the Navy's most relevant technology needs. The NEEC projects vary from researching ship designs for expanded naval operations in the Arctic, to bio-inspired autonomous underwater vehicle designs, to identifying environment-friendly refrigerants for naval applications.

Participation in NEEC also allows professors and their students to work alongside knowledgeable personnel who are familiar with the Navy's technology challenges and to work in the Warfare Centers' unique facilities. Such opportunities are beneficial for everyone involved. They contribute to the growth of naval engineering talent for the Warfare Centers, and they fortify our foundation, which consists of people and partnerships. We look forward to continuing to develop these productive relationships into the future!

Dr. Martin Irvine, Jr., SES
Executive Director
Warfare Centers

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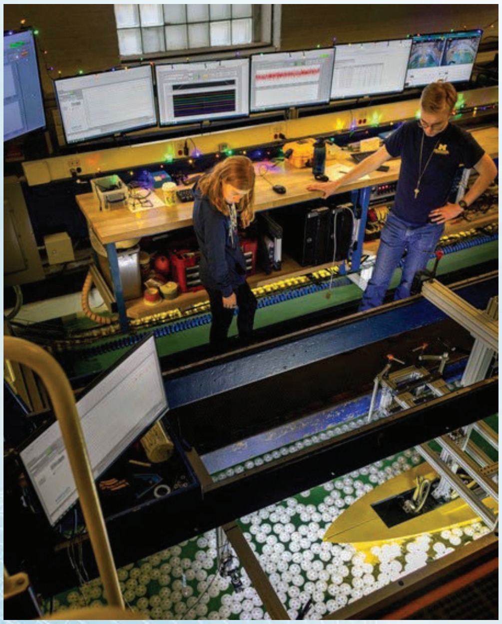

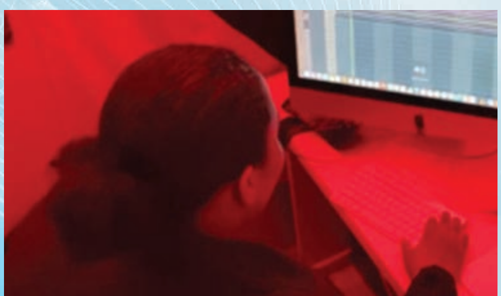

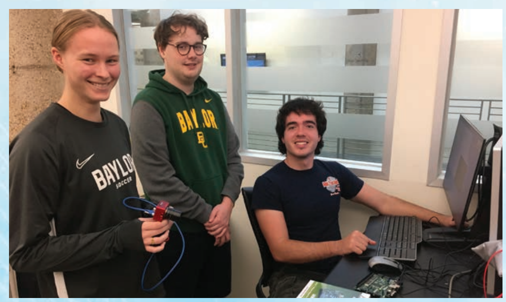


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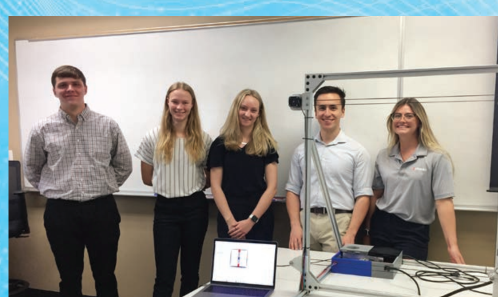
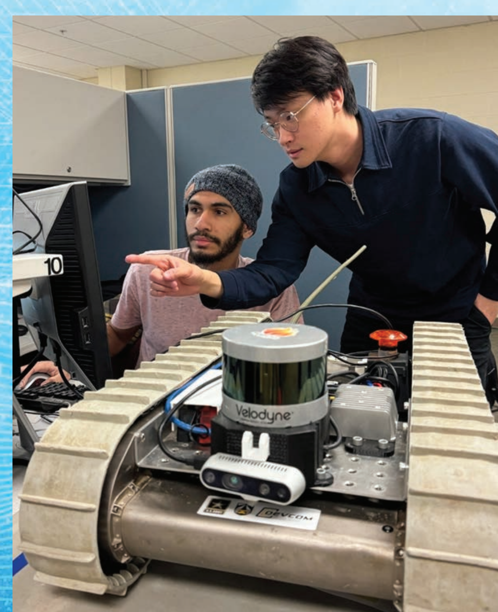


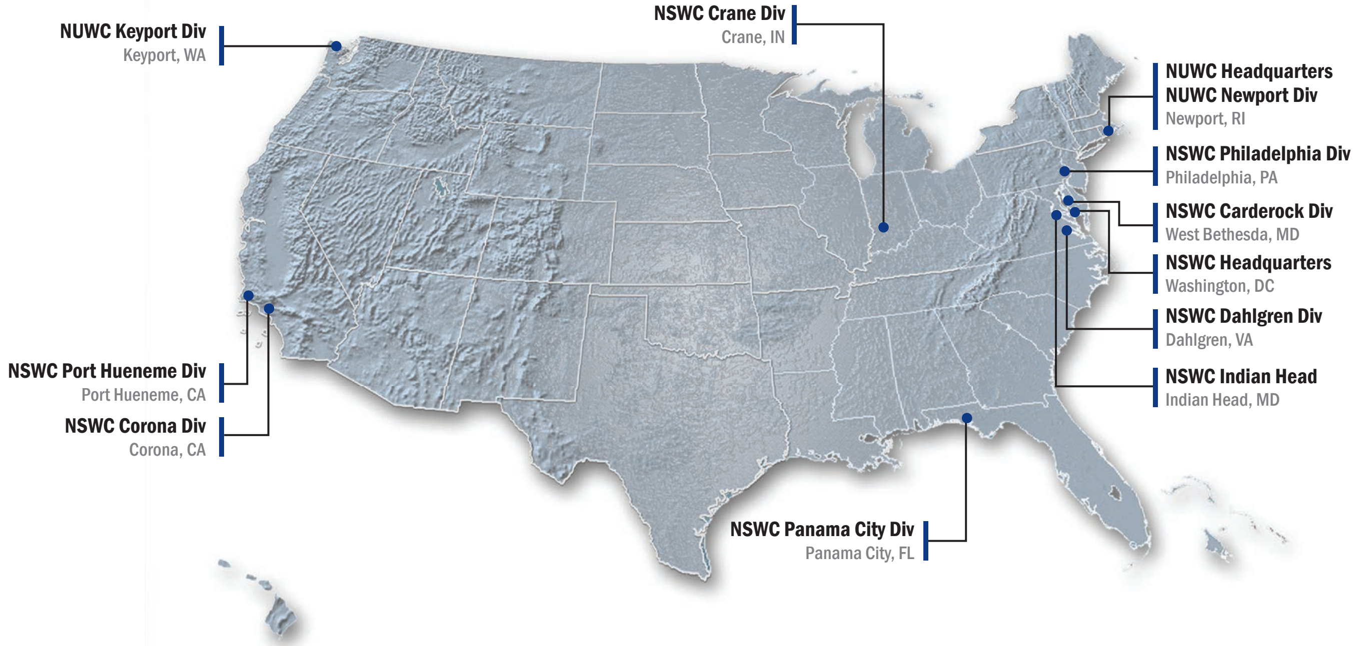

Velodyne

About the Warfare Centers at the Naval Sea Systems Command (NAVSEA)

Scientists and engineers at NAVSEA and the Warfare Centers perform research, build technology-dependent systems, and further develop the technologies used in the U.S. Fleet of ships and submarines. With eight Surface Warfare and two Undersea Warfare sites (Divisions) across the United States, these Warfare Centers supply technical operations, people, technology, engineering services, and products needed to equip and support the Fleet and meet the needs of the warfighter. These Warfare Centers are the Navy's principal research, development, test and evaluation (RDT&E) activities for surface ship and submarine systems and subsystems.

The Consortium

● Warfare Center partners



NEEC Directors

NAVSEA Headquarters NEEC Director:
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Naval Surface Warfare Center Division, Carderock:
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Naval Surface Warfare Center Division, Corona:
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Naval Surface Warfare Center Division, Panama City:
Matthew J. Bays

Naval Surface Warfare Center Division, Philadelphia:
Stephen A. Mastro

Naval Surface Warfare Center Division, Port Hueneme:
Armen Kvryan

NSWC Carderock

Viewmaster for Friction Visualization

Professor:
J. Gregory McDaniel

Students:
- Undergraduate: 2
- PhD: 1

Boston University

The study and understanding of vibrations and acoustics of structures are critical to the design, performance, and maintenance of both surface and undersea platforms. This field is often not covered in undergraduate and graduate engineering curricula, and new hires need to be trained in the unique skills in this field. This project enabled senior thesis and capstone projects, specifically in structural and machinery vibrations, and exposed the students to careers in this field, which is in high demand in the Navy RDT&E enterprise.

This report documents the development of a device which would enable researchers in the field of vibrations to observe a phenomenon in a way that has never been done before. The vibrations that occur at the boundary between two materials dragged against each other has been studied in the past and is of particular interest to the Navy, due to its occurrence in ships and the implications in underwater acoustics. However, these vibrations are at such a small scale that it makes it difficult to capture on camera. In partnership with Professor J. Gregory McDaniel and Professor Enrique Gutierrez-Wing of Boston University, we developed a device that can recreate these vibrations and that is compatible with Trilion's high-speed motion capture system. The device has the ability to fine-tune friction parameters and vary the testing materials.

To gain insight into the normal forces required to produce stick-slip vibration, we created an experiment in which we used the force of a vise to create pressure. With this we were able to create audible vibrations in a bar of steel. We ensured the repeatability of this experiment by machining customized aluminum jaws for the vise.

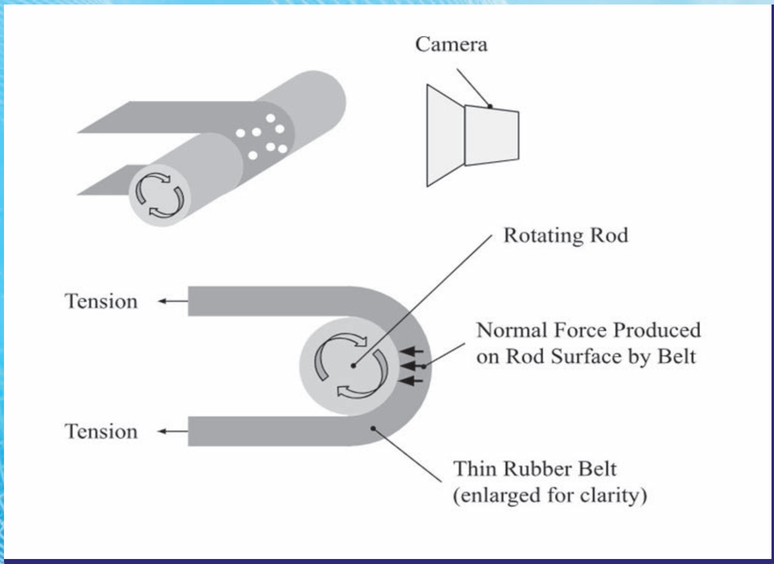


Diagram of the rotating cylinder concept to the upper portion. A ratcheting device was added to keep the belt locked in place at the other end. Clevis pin connections provide convenient sample replacement. Tests are conducted by rotating the hand crank wheel and then pressing a button to trigger measurements.

Plot showing the computed force and the computed rotational speed from the voltage signals.

Senior Design Project in Support of Naval Applications

Professor:
Pierre-Philippe Beaujean

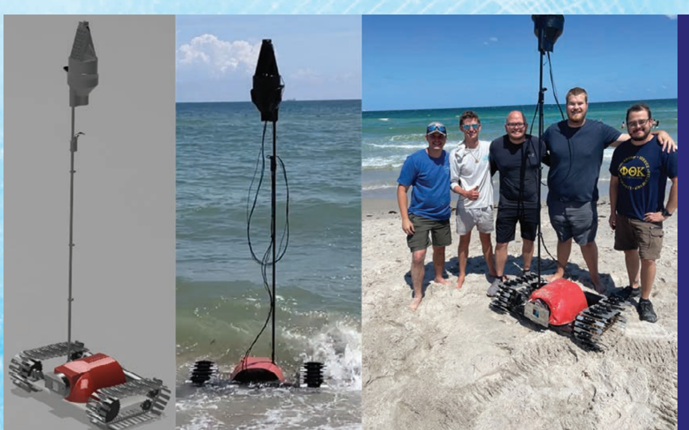
Students:
- Undergraduate: 22

Florida Atlantic University

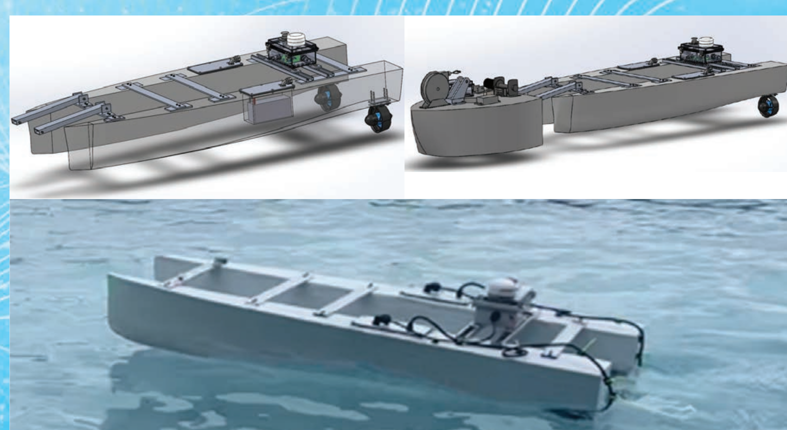
Students in the Florida Atlantic University (FAU) Ocean Engineering (OE) program are working to develop systems of naval relevance during a two-semester capstone senior design project that involves designing, building, testing, and demonstrating complete systems. Strong emphasis is placed on autonomous operations of unmanned vessels and launch-retrieve mechanisms. In completing these projects, the students gain critical experience in mechanical, electrical, software design and implementation of marine systems. In addition, the students learn how to effectively plan their work, execute this plan, operate as a team, and meet deadlines under financial and technical constraints.

The students choose their projects from a collection of topics focused on marine autonomous systems, and they work in teams of 5-6 undergraduate students that are supported by faculty and technical staff. For the reported period of August 1, 2022 to July 31, 2023, four projects were sponsored by the NEEC program:

1. An Autonomous Surf Zone Inspection System.
2. A Bio-Inspired Autonomous Underwater Vehicle with Six-DOF Motion and Station Keeping Capability.
3. An Unmanned Surface Vessel for Water Sampling with Modular Water Sampling Payload.
4. A Containerized and Modular Deployment System for Small Size Surface and Underwater Vessels.



Design, Field Testing, and Team for the Autonomous Surf Zone Inspection System.



Design of the Unmanned Surface Vessel with (top) and without (middle) the Modular Water Sampling Payload. Bottom: Unmanned Surface Vessel during Field Testing.

NSWC Carderock

Design and Evaluation of Naval Vessels for Arctic Operations

Professor:
Kevin Maki

Students:
- **Undergraduate:** 5
- **Master's:** 1
- **PhD:** 2

University of Michigan

The global climate is changing, and human activity in the Arctic region is rapidly increasing. Many nations are interested in energy resources, military presence, shipping, and adventure tourism in the polar regions. The US Navy has limited surface ship capability in Arctic and icy waters, and this project is directed at developing new research ideas and populating the future workforce pipeline for expanded naval operations in the Arctic.

This project studies the loads of broken ice that form on the DDG-51 hull. The students will develop an understanding of how the loads develop and how to provide guidance for safe operation of the existing fleet.

A segmented model is constructed to be towed in an ice field. The ice field is arranged in different configurations, and the model is towed at different speed. The forces on the direct contact area and on the sonar dome are measured independently.

The test campaign was successful, and the students identified the loading in different ice conditions. Significant loads are found due to the ice on the sonar dome. The students presented their research findings at a department seminar at the end of the academic year in April 2024.

The students met with the PI on a weekly basis and then met together to perform tests and work on analysis and their presentation. The students also worked with lab staff to learn how to instrument and set up the model. Three of the students were able to travel to the ASNE Arctic and Antarctic Operations Symposium in Baltimore MD in March 2024. The students met with personnel from Carderock when they visited the department in the fall of 2023.

Students running the destroyer bow model through a simulated broken ice field in the Aaron Friedman Marine Hydrodynamics Lab at the University of Michigan.

The destroyer bow model under test in the simulated ice field (wiffle balls).

NSWC Carderock

Applications of Machine Learning and Other Modern Techniques for Acoustic and Structural Vibration Analysis in Noisy and Complicated Scenarios

Professor:
Natasha Chang

Students:
- **Undergraduate:** 5
- **PhD:** 2

University of Michigan

This project has three tasks that all emphasize experimental work and measured-signal analysis.

(1) Design and conduct axisymmetric transient-impact simulations and experiments that include measurements of air- and water-borne sound radiated from a structure that is fluid-loaded by water on one side to determine the characteristics of the impact and the structure. The intent here is to find ways to remotely characterize impulsive and long-duration noise sources and to determine how fluid loading influences such characterization.

(2) Develop and test hydroacoustic measurement techniques for surface pressure fluctuations caused by wall-bounded turbulent flows. The intent here is to develop better means for measuring a primary source of structural excitation.

(3) Localize vibration sources on a flat metal plate and on a metal cylinder by using measured time series from an array of accelerometers. The intent here is to develop and test data-driven machine-learning techniques, which might be readily deployed on Navy assets, for localizing and characterizing sound and vibration sources.

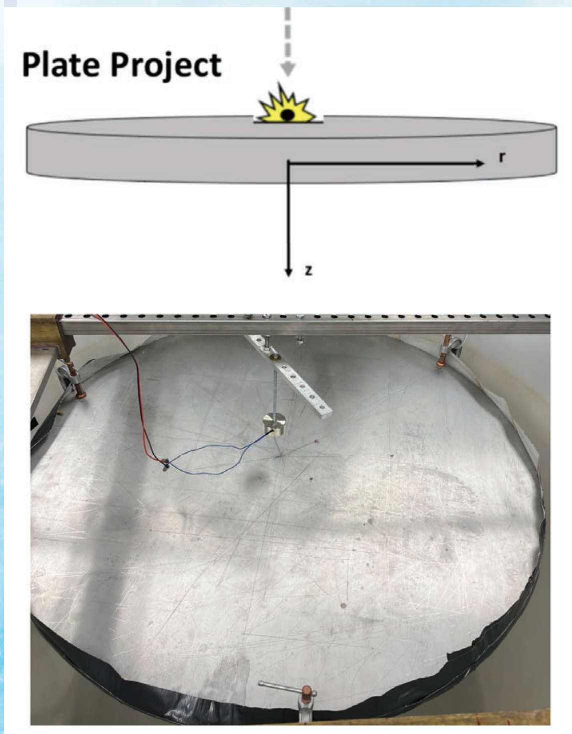
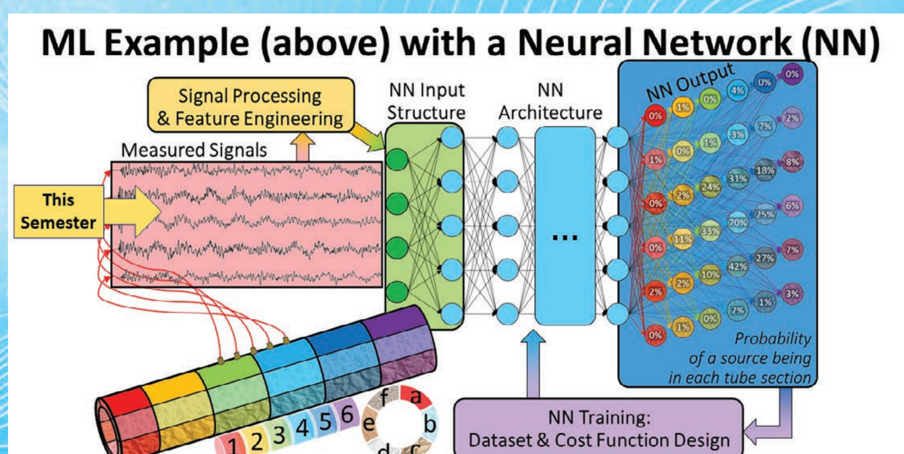


Diagram and photo of flat aluminum plate model used to characterize impact from various sized ball bearings.



Machine Learning/NN diagram representing using ML to analyze the signals from impact on a pipe.

NSWC Corona

RECO-NLP: Low-Power Reconfigurable Computing Architecture for Accelerating NLP

Professor:
Mohamed El-Hadedy (Aly)

Students:
- **Undergraduate:** 2
- **Master's:** 2

California State Polytechnic University, Pomona

This groundbreaking initiative explores the integration of Bidirectional Encoder Representations from Transformers (BERT), a leading-edge Natural Language Processing (NLP) model, with custom drone technologies at California Polytechnic Pomona's Reconfigurable Space Computing Lab (RSCL). By merging a novel flight controller that combines a Field-Programmable Gate Array (FPGA) and a Field-Programmable Analog Array (FPAA), the project aims to enhance drone operability significantly. The dynamic configuration of an FPGA allows for adaptable digital processing, while an FPAA extends this flexibility to analog computing. This innovative approach elevates drone responsiveness and adaptability, leveraging BERT's advanced language comprehension for intuitive, natural language drone commands.

The primary objective of the project is to develop drones that can be controlled through natural language, a feat made possible by BERT's sophisticated understanding of human language. This advancement is expected to make drone operation more accessible and efficient, offering the potential for real-time, adaptive responses to complex instructions and varying conditions. The combination of FPGA and FPAA technologies in the flight controller is instrumental in supporting this goal, promising to revolutionize drone capabilities with improved performance and reliability.

The potential benefits of these technological advancements are immense for the United States Navy. The ability to control drones using natural language processing could revolutionize naval operations, enhancing surveillance, reconnaissance, and tactical flexibility. This technology perfectly aligns with the Navy's requirements for adaptable, robust systems capable of performing in the challenging maritime environment. The project has the potential to transform drone technology and support the Navy's strategic objectives, offering improved situational awareness and operational efficiency.

NEEC Student


NEEC Student


NEEC Student


NEEC Student

Harnessing Quantum Control Algorithms that Utilize and Enable New Machine Learning Applications with Entangled Qubits

Professor:
Bryan M. Wong

Students:
- **Undergraduate:** 1
- **Master's:** 1
- **PhD:** 2

University of California, Riverside

One of the main objectives of this project is to use quantum optimal control algorithms in conjunction with data science approaches to control quantum states in solid-state systems. For an accurate simulation of quantum states in solid-state systems, we have constructed a new software code that incorporates nonlocal exchange effects that go beyond the typical Schrodinger-Poisson treatment, which uses a simple product form of the total wavefunction and suffers from self-interaction errors. During this past year, we have found that the conventional Schrodinger-Poisson formalism overestimates the number of occupied electron levels and overdelocalizes electrons in solid-state heterostructure systems (see Fig. 1). This work is currently undergoing a first revision in a peer-reviewed journal with the anticipation that it will be published soon.

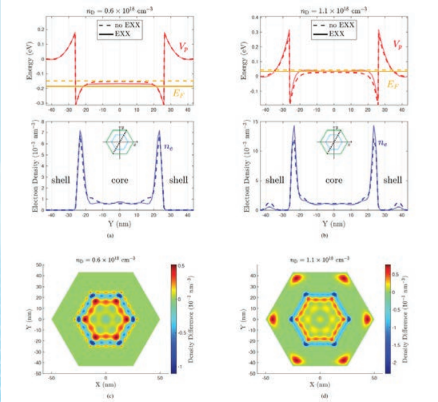
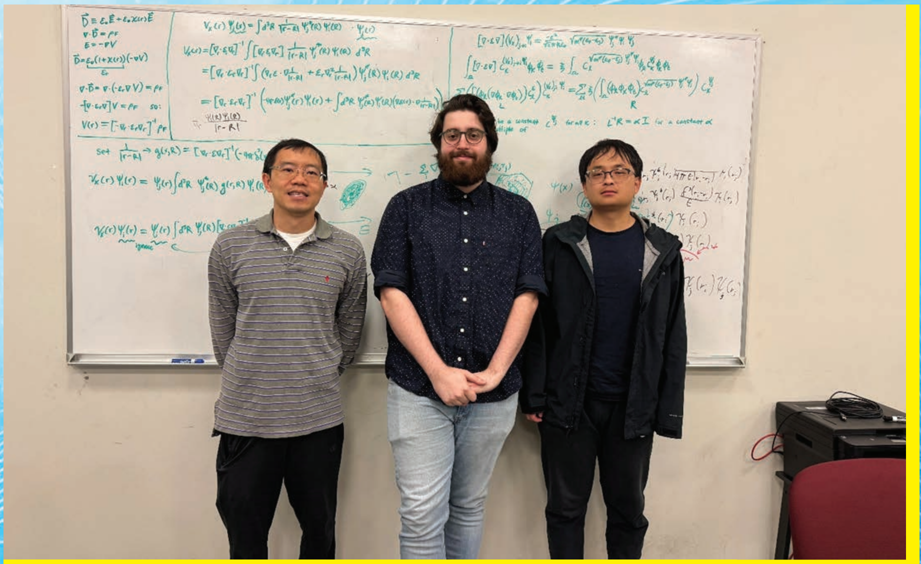


Fig. 1. Potential energy (red lines) and Fermi level (orange lines); (lower panels) electron density (blue lines) for a hexagonal GaN/AlGaN nanowire with a doping density of (a) 0.6 × 10cm-3 and (b) 1.1 × 1018cm-3. Results with exchange are denoted by solid lines, whereas calculations without exchange are shown in dashed lines. The potential energy and electron density were calculated along the dashed line across the diagonal of the hexagon nanowire diagram in the inset. The corresponding electron density differences, ne, no EXX-ne, EXX, are shown in panels (c) and (d), respectively.

Bryan Wong and students carrying out quantum calculations on nonlocal exchange for heterostructure nanowires.



Bryan Wong and students in the Nanoscale and Mesoscale Materials group at UC Riverside.

Adaptive Mapping, Sensing, and Decision Making for Autonomous Underwater Vehicles (AUVs) and Autonomous Surface Vehicles (ASVs)

Professor:
Lantao Liu

Students:
- **Undergraduate:** 2
- **Master's:** 2

Indiana University Bloomington

Our project aims to develop essential autonomous modules to equip Autonomous Underwater Vehicles (AUVs) and Autonomous Surface Vehicles (ASVs) with intelligent capabilities for tackling challenging tasks such as seafloor mapping, ocean monitoring, underwater infrastructure inspection, and exploration of unknown ocean regions, all of which are important Navy application areas. Over the past year, our focus has been on developing solutions for robot perception and terrain mapping.

For instance, an undergraduate senior mentored by a PhD student, dedicated his efforts to enhancing ASV navigation through computer vision techniques, particularly visual object detection. Employing deep learning methods like the YOLO framework, the student tackled issues of data scarcity and reliability to enable real-time visual recognition processing, crucial for applications in autonomous vehicles. Additionally, he also explored and learned system knowledge such as sensor setup and GPS processing to augment ASV functionalities.

Our recently graduated Master's student, supported by NEEC for more than one year, concluded his work on semantic segmentation—a vital aspect of computer vision that involves categorizing each pixel in an image. This work is instrumental for robots to comprehend visual information accurately. He addressed the challenge of creating large-scale datasets for training semantic segmentation models by generating pixel-accurate semantic label maps from images acquired in a high-fidelity simulator. His research culminated in a paper titled "A Simulated Dataset for Forest Scene Understanding," submitted to a robotics conference.

As the seafloor's uneven terrain poses navigation challenges for AUVs, our research focuses on enhancing terrain maps to aid control algorithms. An undergraduate senior, under the mentorship of a PhD student, has been developing Gaussian Process (GP) elevation mapping. This machine learning model estimates surface elevation based on sensor data, providing crucial gradient information for assessing terrain features and traversability.

Undergraduate student working on elevation map reconstruction. The pictures show the student working on preparation of outdoor terrain testing

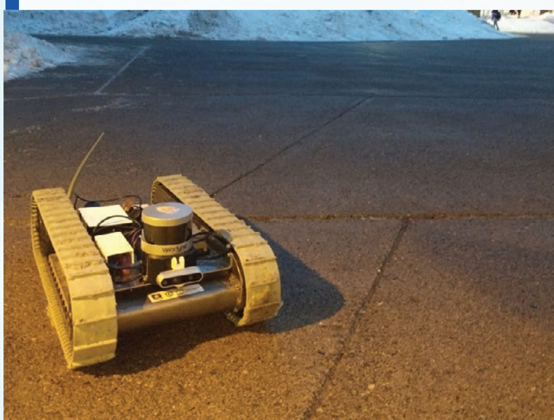
Undergraduate students working on building an ASV. The project is supported by both NEEC and AIMM at Crane.

NSWC Crane

Robust Algorithms for Complex Autonomous Robot Systems

Professor:
Timothy C. Havens

Students:
- **Undergraduate:** 1
- **Master's:** 1
- **PhD:** 2



The Michigan Tech GVRbot navigates and maps the walking paths on Michigan Tech's campus.

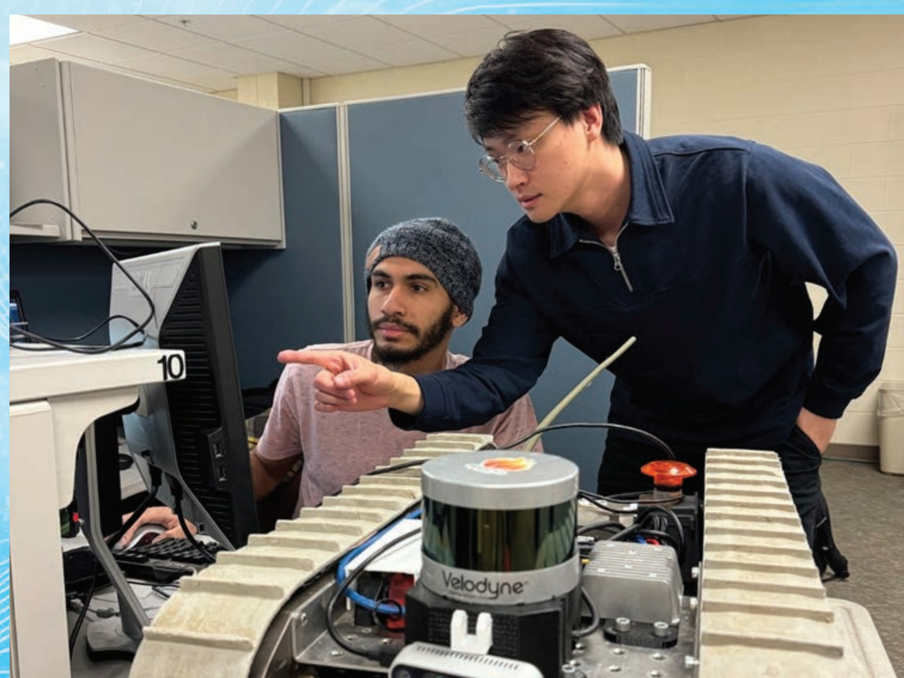
Michigan Technological University

A clear need exists for understanding of autonomy attack and defense strategies at a fundamental level: sensors and software. Adversarial threats exist for many foundational AI algorithms on which higher-level autonomy is based. It is important that the effects of this uncertainty are understood at all levels of autonomy, from sensors to decisions. This project explores and analyzes uncertainty and its ramifications throughout a prototypical autonomous system including hardware/sensing considerations and the entire software stack, focusing on widely-used robot operating system (ROS) algorithms.

Like the arms race exhibited in many cybersecurity developments, counter-AI attack and defense developments are directly linked. Attack strategies can provide insight into new defense strategies and vice versa. Hence, in addition to the study of adversarial uncertainty, we also explore and propose novel robust algorithms / defense strategies. Included in these algorithms and strategies are mitigation methods to invoke when uncertainty is detected at some point within the system.

The counter-AI attack and defense studies are performed both in simulation—e.g., Gazebo—and in real-world experiments with autonomous systems, both terrestrial and marine. To provide a comprehensive analysis of our proposed solutions, we are developing a test bed for evaluating both attack and defense strategies. This test bed will begin with a simulation-based environment capable of simulating an autonomous vehicle with various sensors within a physics engine: Gazebo. This autonomy simulator will be used for agile, rapid development and analysis of results. The second half of the test bed comprises a real autonomy-enabled vehicle placed in a mock-adversarial environment.

Michigan Tech student performs an indoor SLAM experiment using the GVRbot.



Michigan Tech students troubleshoot sensor integration on GVRbot.

NSWC Crane

VerIP: Hardware Support for Securely Leveraging Untrusted Intellectual Property Cores for Mission-Critical SoCs

Professor:
Amro Awad
Aydin Aysu

Students:
- **Undergraduate:** 2
- **Master's:** 2

North Carolina State University

The project explores efficient security mechanisms to integrate untrusted intellectual property (IP) designs in high-assurance System-on-Chips (SoCs). In particular, this project aims to enable the selection from a wide range of IP options while ensuring secure operation all the time through innovative architectural solutions. If this project is successful, it will lead to (1) training qualified students to architect and develop secure-by-design architectures that enabling the integration of the most promising IPs available commercially, (2) reducing the costs for architecting DoD-related SoCs by enabling the integration of 3rd party IPs without introducing any security risks, and (3) influencing the designs of future high-assurance systems that require a short time from high-level architecture to tape-out with usage of the most advanced and available technologies. The project also plans to align its outcomes and deliverables with the new ecosystem that could develop under the CHIPS Act by carefully considering the usage of any 3rd party IPs and ensuring that the proper safeguard logic is in place.

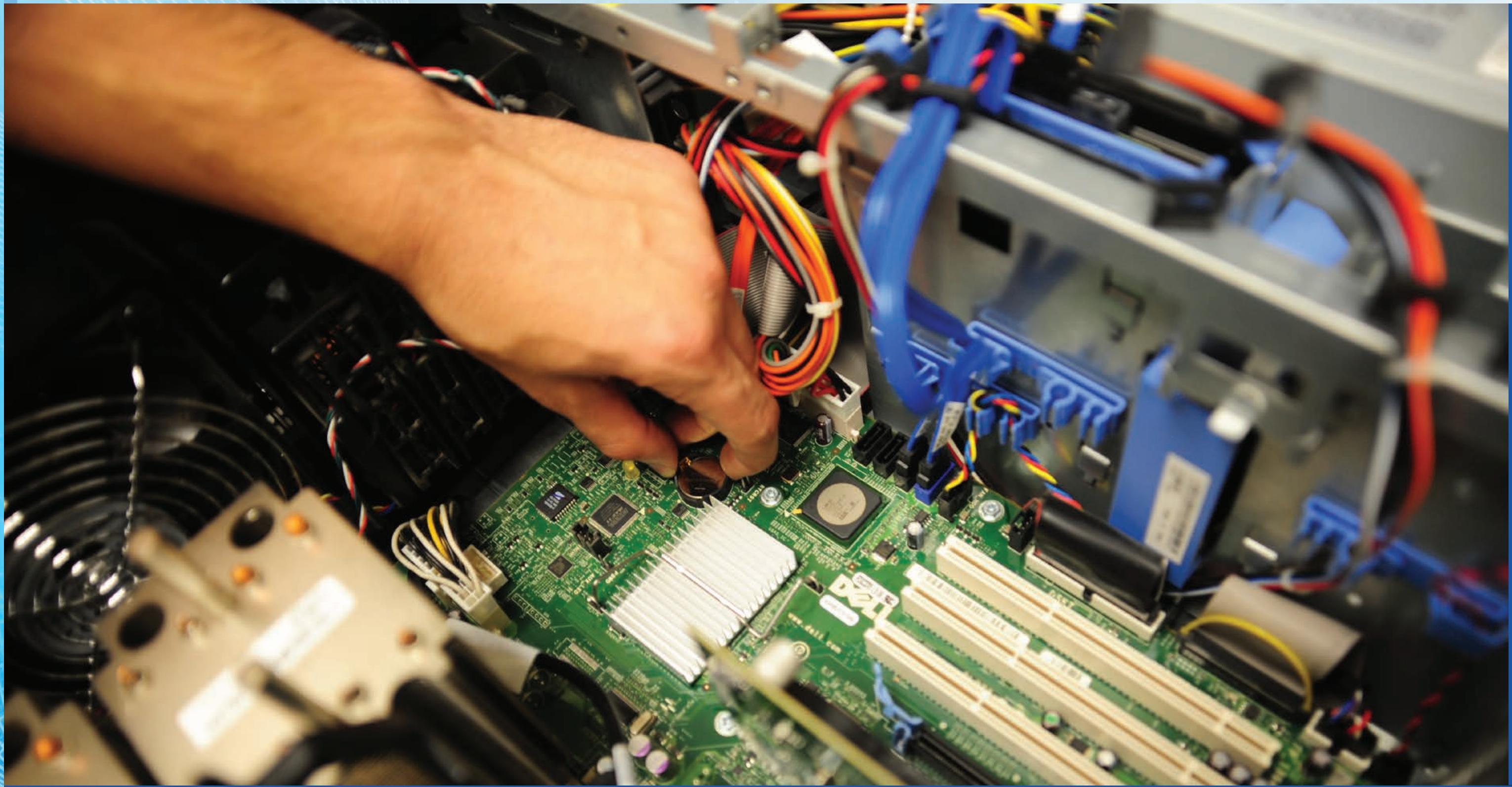


Image courtesy of Defense Visual Information Distribution Service (www.dvidshub.net).

NSWC Crane

Deep Complex-valued Convolutional Neural Networks (DCCNN) for Joint Spectrum Sensing and Channel Estimation

Professor:
M. Can "John" Vuran

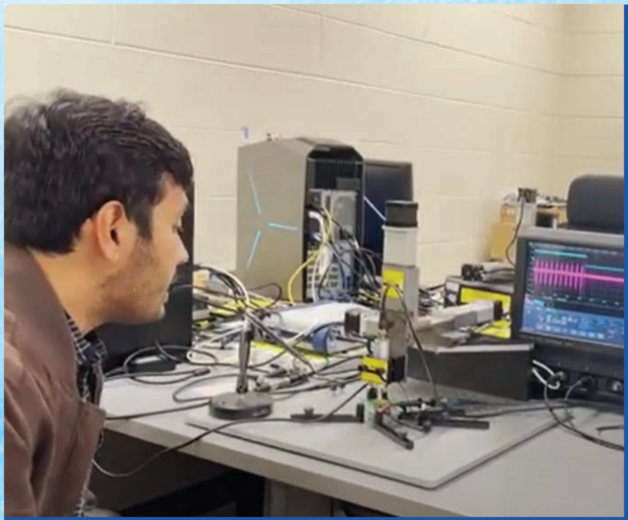
Students:
- **Undergraduate:** 1
- **Master's:** 1
- **PhD:** 1

University of Nebraska-Lincoln

The increasing use of the spectrum by friendly and adversary parties creates a dynamic spectrum environment that is nontrivial to capture through model-driven methods. Furthermore, the site-specific impacts of spatial environments are highly complex for conventional modeling tools, motivating data-driven solutions such as deep learning. Although applications of deep learning in the physical layer of wireless communication have shown remarkable performance, it is unclear whether these approaches can capture complex real-world scenarios by learning the dynamic spectrum and spatial environment. This project focuses on spectrum monitoring with a novel deep learning approach (i.e., complex-valued neural networks) that is shown to capture complex wireless signal representations and learn transformations in wireless signals without explicit models. To this end, we leverage the recent developments in deep learning in terms of complex-valued neural networks, where the inputs to the deep learning model are complex-valued, in contrast to the existing solutions that only handle real values.

The goal of this project is to transform deep complex-valued convolutional neural networks (DCCNN) from their infancy to practical operation in the wild for joint spectrum sensing and channel estimation. To enable persistent electromagnetic spectrum awareness, this project focuses on DCCNN-based joint spectrum sensing and channel estimation algorithms. This is the initial step in predicting and characterizing adversary spectrum utilization (usage, jamming, interference, etc.) for exploitation and EMS maneuver space. The project results support communication activities for spectrum-denied areas and dynamic spectrum sharing for a large group of terminals.

The project fosters a unique interdisciplinary environment for undergraduate and graduate students in the nexus of wireless communications, machine learning, digital signal processing, and experimental research. The proposed solutions are evaluated at the Nebraska Experimental Testbed of Things (NEXTT), a city-scale gigabit wireless network testbed deployed on the UNL campus and throughout Lincoln, Nebraska.



NEEC student

NEEC students

NSWC Crane

Turbulent Transition Over Conical Nose Cones Combining Yaw and Nose Bluntness Effects

Professor:
Eric Matlis,
Aleksandar Jemcov,
Thomas Corke

Students:
- PhD: 6

University of Notre Dame

UNIVERSITY OF NOTRE DAME

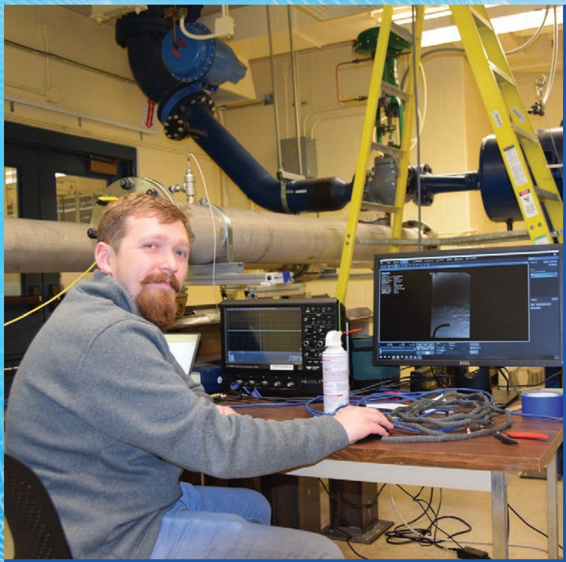
Transition to turbulence for cones or lifting bodies at angle of attack in hypersonic flows is influenced by the development of both Second Mode and cross-flow boundary layer instabilities, which may exist simultaneously at intermediate yaw angles. Potential interactions between these two mechanisms can accelerate transition. Cross-flow dominated transition can be controlled with the use of discrete roughness elements applied to the surface. This work is investigating the potential for interactions, which will provide the framework for transition prediction.

Year 1 began with simulations to identify the frequencies of interest in the Second Mode. These simulations began with the calculation of the mean base flow at angles of attack from 0 degrees to 4 degrees on a 7-deg half-angle right circular cone. A similarity solution was used to verify the results at 0 deg angle of attack. The NASA stability code LASTRAC was used to analyze the stability. The results predict a second Mode frequency at 200 kHz.

Year 2 involved an experiment at the Air Force Academy Mach 6 Ludwieg tube tunnel. Kulite dynamic pressure sensors were used to resolve the azimuthal and axial variation in mean and fluctuating total pressure in the boundary layer at a predetermined height above the wall. The stagnation conditions were designed to match the simulations at a Unit Reynolds of 10M/m. Yaw angles between 2 and 4 degrees were examined. These measurements revealed the presence of stationary cross-flow vortices at azimuthal angles of roughly 45 degrees from top dead center, and unsteady disturbances near 200 kHz consistent with Second Mode instabilities.

In Year 3, the experiment is being moved to the newly commissioned Notre Dame Hypersonic STEM Lab facility. This facility includes a Mach 6 Ludwieg tube, a Mach 4 expansion shock tunnel, and a Mach 3 blow-down tunnel. The Ludwieg tube tunnel provides comparable experimental conditions to the Air Force Academy's Ludwieg facility. The main objective is to add discrete roughness to control the cross-flow instability and plasma disturbance generators to control Second Mode instabilities while conducting streamwise, azimuthal, and wall-normal off-wall measurements. Any nonlinear interactions will be documented with the Kulite sensor.

Notre Dame freshman besides ND Hypersonic STEM Lab Mach 6 Ludwieg-tube tunnel. Student is designing a pitot rake to characterize flow uniformity in the Mach 6 nozzle.



Notre Dame PhD candidate demonstrating fast schlieren imaging system he developed for the ND Hypersonic STEM Lab Mach 3 blow-down tunnel.

Notre Dame Hypersonic STEM Lab Team.

NSWC Dahlgren

Low-Bandwidth Selective Transmission of Rare Events

Professor:
Mahadev Satyanarayanan

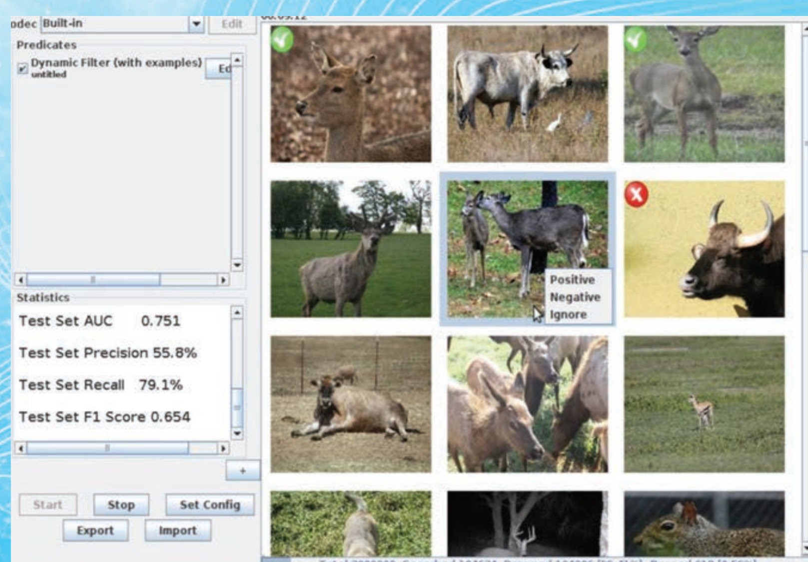
Students:
- PhD: 3

Carnegie Mellon University

Autonomous unmanned probes such as aerial drones, satellites, interplanetary spacecraft, and underwater drones collect vital training data for machine learning (ML) in domains such as planetary exploration, oceanography, climate change tracking, wildlife conservation, and national security. Captured data is returned via wireless network transmission. In such missions, there is often a severe mismatch between the incoming sensor data rate and the much lower backhaul bandwidth to the Internet. Today, this ratio can easily reach 1,000 to 10,000 or more. For example, a 4K/30FPS video camera has a bandwidth demand of roughly 30 Mbps; however, the physics of acoustic communication in underwater sensing limits bandwidth to a few tens of kbps. The knowledge acquisition goal of such expensive and difficult missions poses a different challenge. The most valuable knowledge is often rare. For example, in marine biology, the goal may be to discover the habitat range of a newly-discovered deep-sea species for which just a few images are available. This trifecta of extremes (low bandwidth, class imbalance, and unlabeled data for a novel target) leads to a "perfect storm" for remote sensing. How does a probe ensure that precious bandwidth is not wasted?

To address this problem, we are exploring a self-improving selective transmission system called Hawk. This system complements few-shot learning (FSL) with an iterative workflow called Live Learning that seamlessly pipelines semi-supervised learning (SSL), active learning, and transfer learning, with asynchronous bandwidth-sensitive data transmission to a distant human for labeling. By transmitting a small subset of the enriched sensor stream, new true positives (TPs) can be discovered via human labeling. These can be used to grow the training set and re-train the model. Over many rounds, this iterative workflow is very effective. Hawk supports diverse deep neural network (DNN) designs and training strategies. Our experimental results show that even at a bandwidth of 12 kbps, Hawk is effective on data from drone surveillance, planetary exploration, and underwater sensing.

Mahadev Satyanarayanan and students.



Screenshot of Hawk Labeling Interface.

Christopher Newport University

Capability-based Synthesis for Intelligent Automation

Professor:
David C. Conner

Students:
- **Undergraduate:** 4
- **Master's:** 1

This project defines and develops capability specifications of artificial intelligence (AI) components used in autonomous systems. These specifications permit automatic synthesis of correct-by-construction high-level behaviors to enable intelligent automation of complex systems. This research will develop and apply these capability-based synthesis techniques to define autonomous behaviors using a combination of Hierarchical Finite State Machines and Behavior Trees. The approach will be demonstrated using the Data Distribution Service (DDS)-based Robot Operating System and the Flexible Behavior Engine. This provides a demonstration of the capability-based synthesis approach and provides an open-source platform for training new users in the tools of automatic synthesis, validation, and verification of autonomous system behaviors.

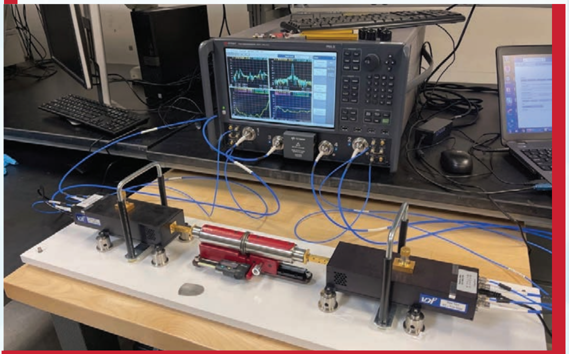
Image courtesy of Defense Visual Information Distribution Service (www.dvidshub.net).

NSWC Dahlgren

W-band Radome Material Characterization

Professor:
Douglas H. Werner

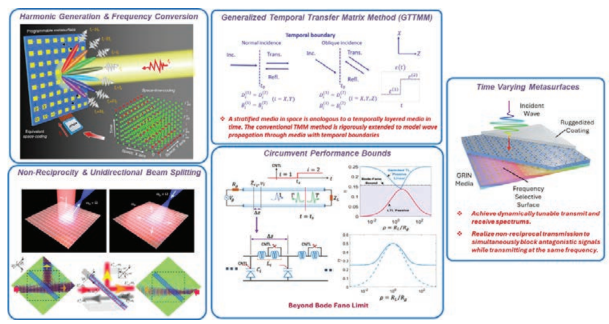
Students:
- Master's: 2



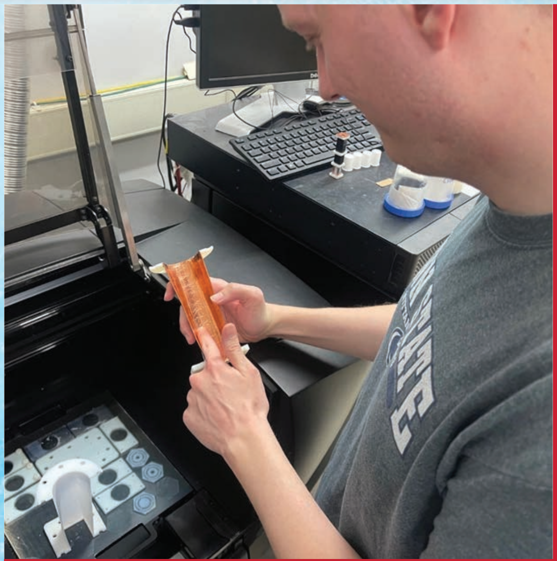
Photograph of the experimental setup for testing new material samples at W-band (75-110 GHz) frequencies.

Pennsylvania State University

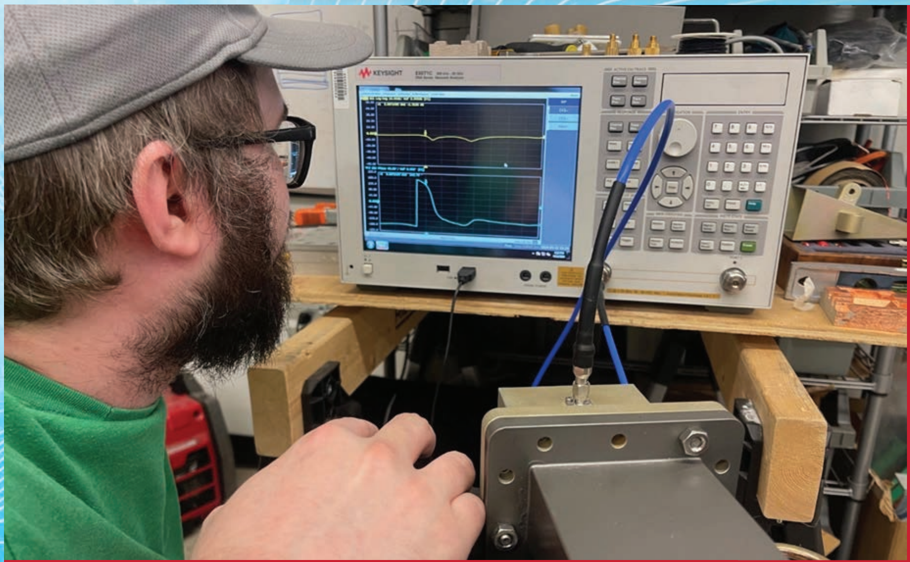
The current NEEC program is a comprehensive effort including literature surveys, advanced multi-physics-based modeling/simulation, and subsequent design phases of enhanced conformal structures that extend the performance of current antenna systems. Experimental characterization of novel materials is a key process that guides the modeling and simulation efforts; it also gives valuable insight into the key radio frequencies (RF) properties and their effects on low-frequency and high-frequency ruggedized antenna radome systems essential for Navy applications. At its core, this endeavor seeks to address critical challenges faced by the Navy, particularly in the realm of radome technologies operating from as low as the C-band to as high as the W-band spectrum. Antenna radomes are integral components of radar and communication systems that shield sensitive electronics from environmental effects. These structures demand robust mechanical solutions that withstand harsh environments while maintaining electromagnetic functionality. This multi-domain operational environment requires advanced computational methods to explore the requisite design space. The outcomes of this program can enhance the Navy's technological capabilities by incorporating enhanced functionality into radome structures, allowing extended performance such as one-way transmission, beam-steering enhancements, or frequency notching to remove coupling to neighboring systems, thereby reducing interference.



By incorporating additively manufactured GRIN systems with advanced time-varying technologies, unparalleled performance capabilities could be unlocked. Further developments can include the multi-material additive manufacturing of both dielectrics and conductive components to allow more diverse design concepts.



PSU PhD student reviewing the surface finish of a copper-plated additively manufactured component.



PSU PhD student reviewing the magnitude and phase performance of a metamaterial unit cell operating within a waveguide environment. This data is then used to refine electromagnetic simulation tools that are essential to guide the development of conformal radome elements.

NSWC Dahlgren

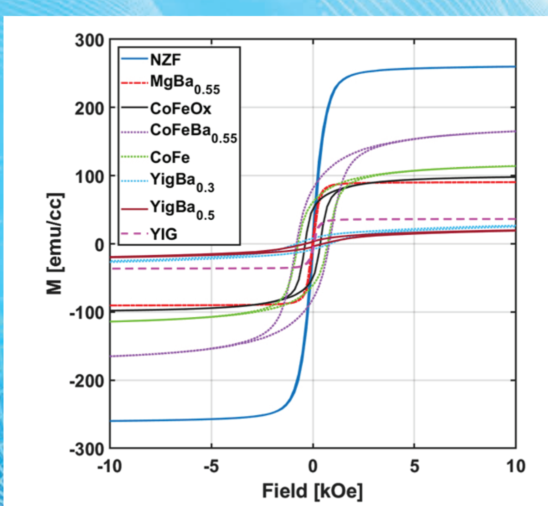
Dielectric Breakdown in High Voltage Power Systems/ Physics Behind Energy Storage in Pulsed Power Systems

Professor:
Allen Garner

Students:
- PhD: 2

Purdue University

Material characterization is crucial to understanding and predicting pulsed power system performance. Hysteresis curves using vibrating sample magnetometry (VSM) for custom materials were measured to allow for the extraction of material permeability, retentivity, magnetization saturation, coercivity, and hysteresis loss. The resulting parameters can be used to help guide the designer when selecting the material that is to be implemented into a system. For example, materials with higher magnetization saturation may generate higher-frequency oscillations compared to their low magnetization saturation counterparts in nonlinear transmission lines systems, while materials with narrow hysteresis curves indicate lower hysteresis loss. The impact of temperature on the magnetic behavior was analyzed by obtaining hysteresis curves from 100 to 400 K.



Measured magnetization curves for the manufactured ferroic/multiferroic ceramics.

Experimental setup for in-plane vibrating sample magnetometry measurements.

NSWC Dahlgren

Intelligent Automation Through dynamic Networks and Mulitlinear time-Series Analysis

Professor:
Randy C. Hoover,
Kyle Caudle,
David Marchette

Students:
- Master's: 2

South Dakota Mines

SOUTH DAKOTA MINES

With continued increases in distributed electronic data, dynamic spatiotemporal networks have received a lot of attention from the research community in recent years. In many "distributed systems" problems, the key idea is to extract the meaningful information from data while ignoring the noise. For example, given a collection of distributed naval weapon systems with the ability to send/receive information, one might wish to understand a) how to model the entire network of data transmission accounting for the intermittent nature of communication failure and b) how to predict these transmissions in a probabilistic manner as a result of internal or external events.

Accurate modeling and analysis of such data provides insight into discovering baseline distributed system behavior and how this behavior changes in response to environmental factors. After building accurate dynamical models, naval researchers and warfighters could intentionally disrupt the model to gain insight into the network's dynamic response to both internal and external events.

This NEEC project aims to explore the use of graph representation learning alongside multilinear time-series modeling to understand and model such complex networks. The overarching goals are to develop novel algorithms to accurately account for the dynamic nature of complex networks, provide simulation tools to validate these algorithms, and apply these algorithms to different naval applications to advance naval readiness and support the naval warfighter.

NEEC advisor Dr. Randy C. Hoover (right) discusses some results from multigraph forecasting with his NEEC student (PhD Candidate in Data Science and Engineering).

MinneMUDAC Team (The Data Miners) at the Minnesota Twins Stadium during the competition.

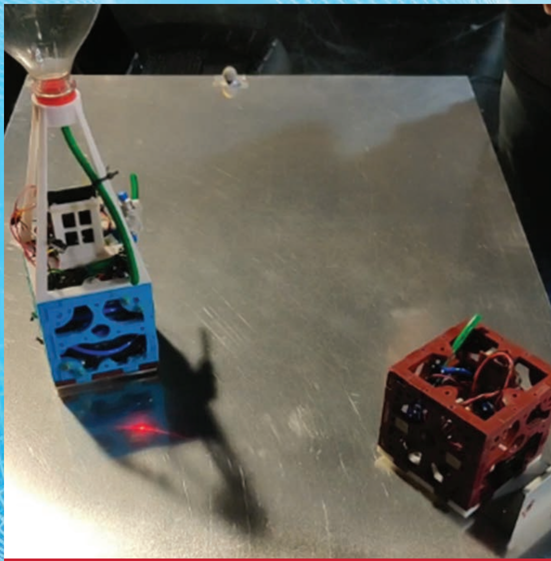
NSWC Dahlgren

Sentient Engineering Autonomy: Learning, Intelligent and Optimal Naval Systems (SEALIONS)

Professor:
Manoranjan Majji,
Duan Chang

Students:
- **Undergraduate:** 2
- **PhD:** 2

NEMOS solid model and prototype NEMOS system.

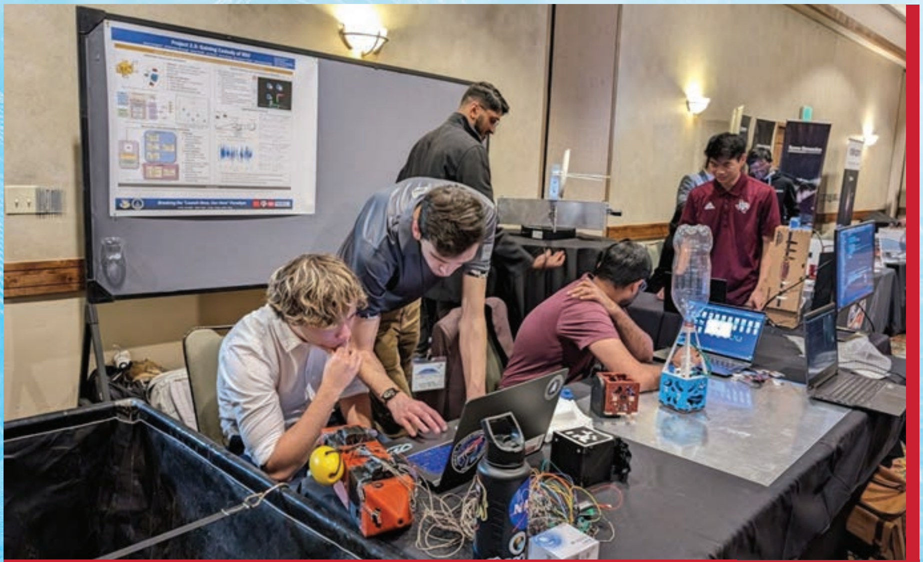


Transforming Proximity Operation and Docking System (TPODS) guidance and control form a basis for NEMOS autonomous operations.

Texas A&M University and Prairie View A&M University

Sentient Engineering Autonomy: Learning, Intelligent and Optimal Naval Systems (SEALIONS) is a framework to evaluate the utility and performance of diverse sets of artificial intelligence and machine learning (AI/ML) tools to autonomously operate unmanned systems used by the US Navy and US Marine Corps. SEALIONS framework will enable an automated prescription of the AI/ML ingredients to carry out the communication, control, guidance, and navigation functions of the autonomous systems operating in littoral environments. Component AI/ML tools are implemented and integrated to perform a mission function, generating performance data from representative model simulations and using flight experiments, and using data-driven modeling approaches to quantify the performance of the component selection. The conditional performance measure then supports an outer-loop learning process to generate prescriptions for future autonomous system design. In addition to providing a wholistic tool to carry out sensitivity analyses of the mission performance as a function of the component algorithm choices, the SEALIONS framework also serves as a first-cut performance certification mechanism for autonomous systems.

To demonstrate the utility of the SEALIONS framework, the team worked on two fronts. Subsurface marine vehicles were developed and prototyped by the team to serve as distributed multi-agent systems that can demonstrate the utility of automated AI/ML mission planning tools using hardware prototypes. These units are called Nautical Environment Maneuvering and Operating Systems (NEMOS). The NEMOS testbed forms a tool to demonstrate sub-surface multiagent autonomy capabilities. Parallel efforts were invested to develop AI/ML tools for complex task planning, management, and surveillance. The PI worked closely with the NSWC Dahlgren mentor to use auto labeling, automated image composition and rendering tools to support complex weapon system guidance and control algorithm development.



NEMOS demonstration in a water tank at the 46th Rocky Mountain GNC Conference and Exhibit. Students can be seen working on the prototype demonstrations at the exhibit.

NSWC Dahlgren

Evaluation of High Speed Rotating Machines in Shipboard Power Systems

Professor:
David Wetz

Students:
- **Undergraduate:** 3
- **PhD:** 1

University of Texas at Arlington

This work is aimed at characterizing electrical generators that have multiple output windings and employ mechanical flywheel energy storage to maintain inertia during high-power transient load events. The Navy is interested in how the coupled windings will influence each other under transient conditions. These transient conditions will affect relevant electrical parameters such as power quality and will inform the extent to which coupled windings influence each other.

Methods to provide more stability to the power quality such as flywheel technology are also being studied. The employment of kinetic energy, in the form of high-speed rotational energy storage, will buffer the dynamics of transient loads while adding volumetric and scalability benefits.

Student connecting a flywheel-coupled multi-output generator's controller to synchronize with UTA's test bed.

Students monitoring flywheel-coupled motor generator sets for power quality measurements under various pulsed load conditions.

Dielectric Breakdown in High Voltage Power Systems

Professor:
David Wetz

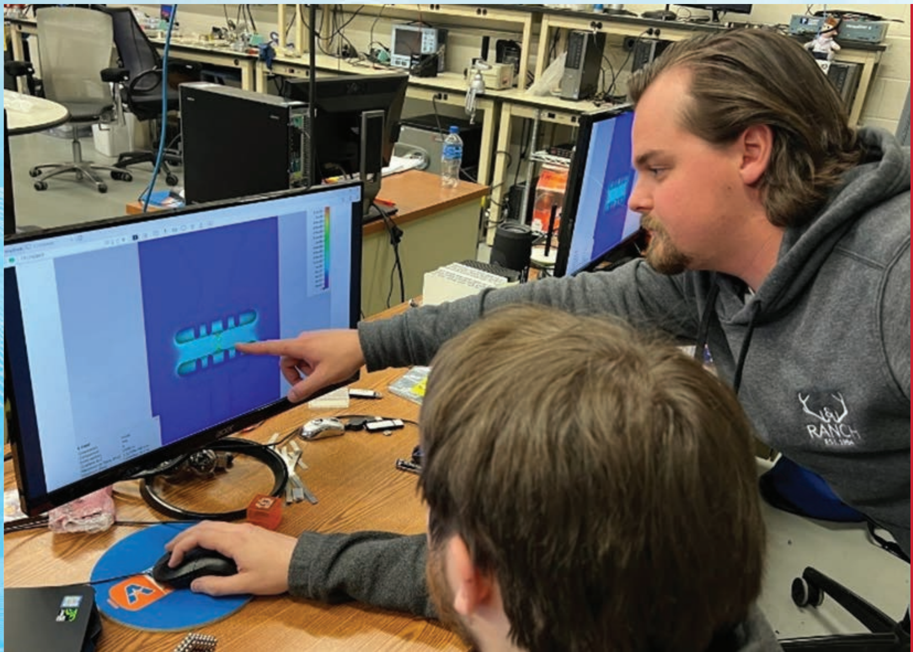
Students:
- **Undergraduate:** 2
- **PhD:** 3

University of Texas at Arlington

The directed energy (DE) systems the Navy is working so hard to field all rely on high voltage dielectric insulation to operate reliably and safely. Insulation of higher-voltage pulsed power supplies usually relies on transformer oil, de-ionized water, or electronegative gas, all of which introduce significant engineering challenges and restrictions. The intent of this research is to study alternative solid dielectric insulation materials that can be used throughout high voltage pulsed power systems. There are previously documented research efforts that have shown the ability to alter the primitivity of potted dielectrics using additives, but little study is presented beyond measurement of their dielectric properties using typical low voltage characterization equipment. Additively manufactured materials and processes are being introduced commercially at a rapid pace, and little is documented on studying their viability as insulators in high voltage pulsed power systems. This research effort has a couple of objectives. The first is to identify unique potted dielectric materials and mixtures that can grade the electric field smoothly between materials of varying permittivity to reduce field enhancements and the probability of breakdown. The second is to study dielectrics with very high permittivity for employment in nonlinear transmission lines (NLTLs). The third is to further study additive manufacturing methods and materials that can be used as high voltage dielectric insulators. The aim is to reduce the weight, volume, and requirement for transformer oil in fielded pulsed power systems. A high voltage pulsed power testbed has been set up and is being used to characterize the pulsed dielectric strength of potted and thermoset plastic dielectric materials with the aim of producing replacements for transformer oil in the near term.

Student collecting permittivity data using a vector network analyzer (VNA)

Student making samples.



Students studying finite element modeling results.

High Power Laser Studies of Thermal Oxidation and Ablation Properties of Ceramic Matrix Composite Materials for Hypersonic Application

Professor:
Mool C. Gupta

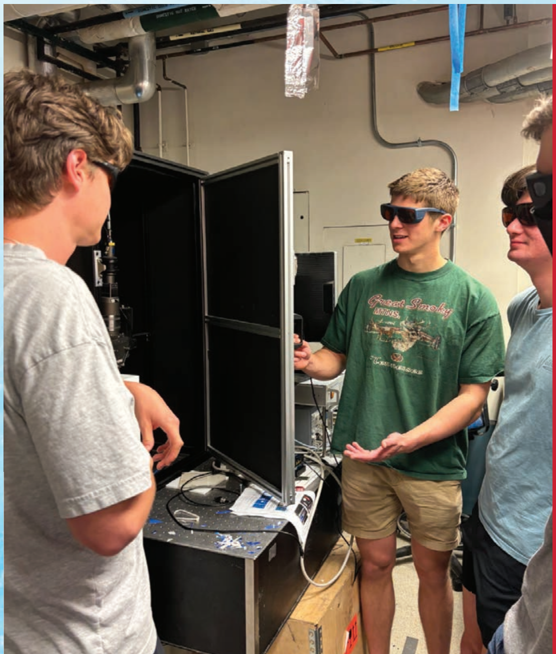
Students:
- Undergraduate: 5

University of Virginia

We are using lasers to cut precise holes in silicon carbide (SiC) ceramic matrix composite, to attach a sapphire window to allow infrared radiation through, and test, with a high-powered laser and fiber optics, if this joint can withstand a hypersonic environment. We have sourced samples of a ceramic composite, SiC, from Northrop Grumman, which is currently used for hypersonic applications. The sapphire window allowing infrared radiation through would allow sensors (the fiber optics) to "see" a thermal image of the environment around the hypersonic vehicle.

The Navy can use this technology on their own hypersonic vehicles and missiles, as those currently developed for defense modes need to be able to sense what is around them for navigation, data acquisition, and targeting. Most materials cannot withstand hypersonic environments and evaporate when immersed in extremely high temperatures, which is why ordinary instrumentation and attachment methods to the aircraft are not feasible. Traditional bonding methods for materials that can withstand hypersonic environments require the use of high-temperature furnaces, which is not a viable option in the context of a large aircraft. To integrate sensor technology with the surface of aircraft, a more portable and programmable method is ideal, such as our proposed method using high-powered laser brazing.

Our research has five overall steps: use precise pulsating lasers to cut and micromachine the extremely hard SiC, use defocused lasers to heat and braze a cobalt-based paste that bonds the sapphire window to the SiC sample, use temperature-resistant cement to attach a fiber-optic cable to the underside of the sapphire window, and test the finished product under a 4kW laser (to simulate hypersonic heating) to examine whether the fiber optics can create a thermal image of their environment. Once this bonding method is optimized for strength and efficiency, the Navy will have a reliable way to integrate imaging sensors into any future hypersonic vehicle they wish to deploy.



4kW laser hypersonic simulation.

Spectroscopy experimentation using silica optical fibers.

Model-Based Mission Engineering Analysis to Improve System of Systems Decisions

Professor:
Peter Beling,
Paul Wach

Students:
- Undergraduate: 4

Virginia Polytechnic Institute and State University

Our project explores the use of large language models (LLMs) for the generation of Systems Modeling Language (SysMLv2) code and the establishment of verification and validation (V&V) metrics to assess the LLM output. It aims to expedite and reimagine digital transformations through the exploration of LLM capabilities. Our research findings highlight the level of proficiency of LLMs in SysMLv2 code generation. It also emphasizes the need for fine-tuning and prompt engineering strategies to ensure better accuracy of LLM generated output. Our future work includes expanding the knowledge base of LLMs' understanding of SysMLv2 syntax and optimizing LLM performance for various diagram types.

Virginia Tech National Security Institute students collaborating on their NEEC project that explores the use of LLM for model-based mission engineering.

NSWC Dahlgren

Data Fusion for Ship Wake Detection

Professor:
Justin Kauffman,
Daniel Sobien

Students:
- **Undergraduate:** 5
- **Master's:** 1

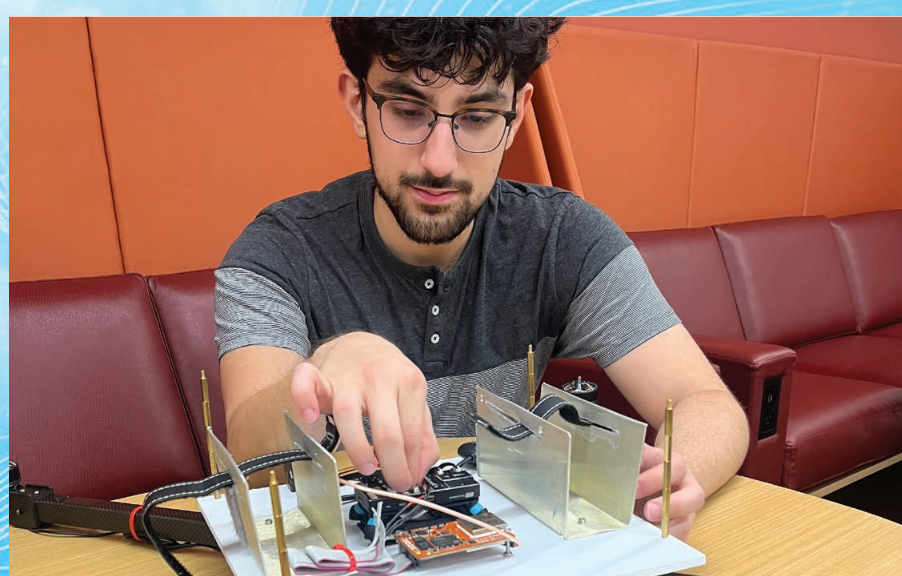
Student soldering components for the synthetic aperture radar (SAR) camera.

Virginia Polytechnic Institute and State University

The team is investigating multiple methods for fusing ship wake remote sensing data to increase the probability of detecting ships based on their wakes. Previously, we have pursued using radon transforms on real-world synthetic aperture radar (SAR) data to identify ship wakes. We are actively pursuing data fusion algorithms that combine heterogeneous sensors, SAR and infrared (IR), as well as different SAR bands, uncertainty quantification (UQ) of wake classification models, transfer learning techniques on models that have been trained on low fidelity simulated data, and data augmentations to drive differences between training and testing data sets for additional transfer learning. The team is also finalizing the design and construction of a custom drone-mounted SAR sensor to collect real-world data on a custom remote-controlled ship. The outcomes from this research investigation are expected to have high relevance to the Navy and Joint Services mission spaces through the increased awareness and characterization of the electromagnetic environment that directly impacts the relevant and actionable information for commanders. For the specific application of ship wake detection, the sensor data fusion algorithms are being rigorously tested and assessed for increased probability of detection and decreases in false alarms.

Building sensor data fusion algorithms has enabled the team to establish baseline metrics while also studying operational conditions that mimic omission or degradation of input streams through data augmentations and differences in data fidelity, demonstrating the importance of transfer learning to cover out-of-domain data. The team studied various augmentations and considered a surrogate study of different simulation fidelities to mimic simulated to real-world data and demonstrated the performance impacts on out-of-domain data; both studies were published in AIAA Scitech in January. The IR and SAR+IR data fusion work was highlighted in a PhD dissertation. The team has also been demonstrating approaches—Bayes Neural Networks and UQ via dropout—for UQ of the classification models by obtaining baseline results for single SAR band wake and no-wake classifications before moving on to multiple SAR band inputs. Finally, we have been building a custom drone-mounted SAR sensor to obtain data on ship wakes produced by a remote-controlled boat.

Student working on the custom drone that will carry the synthetic aperture radar (SAR) camera.



Student working on the custom drone that will carry the synthetic aperture radar (SAR) camera.

NSWC Dahlgren

Virginia Polytechnic Institute and State University

Spectral Warrior

Professor:
William "Chris" Headley, Alan Michaels

Students:
- **Undergraduate:** 12
- **Master's:** 1

The goal of the Spectral Warrior project is to leverage state-of-the-art virtual reality software and hardware to educate students, government employees, and Navy service members about advanced wireless communication concepts through improved visual representations of the underlying concepts, which are largely invisible to the naked eye in the real world. We are working with NSWC Dahlgren to gamify this learning through the use of a "Radio Frequency (RF) Escape Room" virtual reality (VR) concept in order to increase engagement, knowledge retention, and understanding of Navy RF applications with a particular focus on radio frequency phased array technologies.

Spectral Warrior demo

Spectral Warrior demo

Spectral Warrior demo

Machine Learning Algorithms for On-Ship Radar Clutter Mitigation

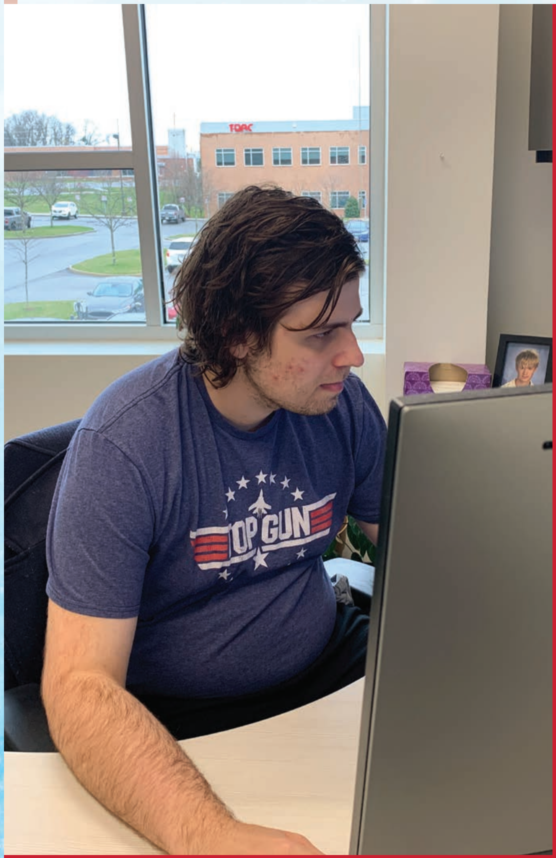
Professor:
Justin Krometis,
Dan Sobien

Students:
- Undergraduate: 1

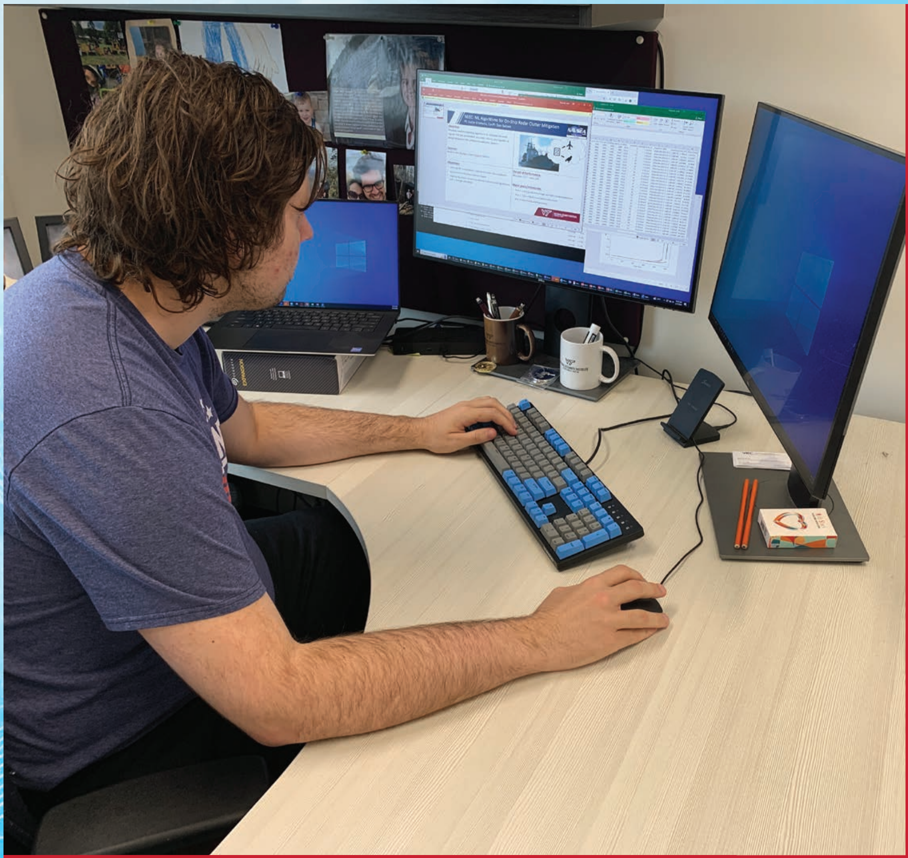
Virginia Polytechnic Institute and State University

Understanding the radar signatures of ambient objects and how to differentiate them from targets that the radar is tasked to detect has been an important topic in the design of air defense systems for decades. Radar clutter is the scattering of signals off of objects that are secondary to the mission of the system and have the potential to obscure or draw attention away from objects that the radar system is tasked to detect. These objects can either be surface-based, such as mountains, buildings, or sea spikes, or airborne/volumetric, such as precipitation, birds, insects, or chaff.

This project seeks to develop machine learning-based algorithms for mitigating clutter in shipboard radar systems. Working with radar data and in collaboration with experts at the Naval Surface Warfare Center Dahlgren Division, project researchers seek to develop an approach to characterizing radar signals that is automated, accurate, and robust. The long-term goal is to build an algorithm capable of being integrated into shipboard collection systems to improve the Navy's situational awareness and translate big datasets into a strategic advantage.



Student working on the development of machine learning-based algorithms.



Student working on the development of machine learning-based algorithms.

Enhanced Matching for Electrically Small Antennas and Arrays with Machine Learning

Professor:
Bradley Davis

Students:
- Undergraduate: 8

Virginia Polytechnic Institute and State University

This program will address several areas of considerable interest in spectrum operations for naval platforms: electrically small antennas, phased arrays, antenna interaction with the local environment, and the impact and applications to electronic warfare (EW) and signal intelligence (SIGINT) operations. The research effort for this program will quantify and explore the application of machine learning (ML) to support improved antenna match characteristics and capture ML's interaction with mission objectives, which may include spectrum monitoring, target detection, tracking, fire-control, and more. This program is structured to support a group of undergraduate researchers and to develop these students' interest in pursuing employment or graduate education in spectrum operations (nominally, six to eight students). The effort will maintain strong ties with the Naval Surface Warfare Center Dahlgren Division to encourage the greatest interest in internships. It will invigorate fading university interest in electromagnetics applied to EW, radar, and communications, which are pervasive in the Navy.

VT Students working with Near-Field Scanner.

Students constructing tape-measure dipole antennas.

Students setting up to test 3x3 array antenna.

NSWC Dahlgren

NEEC Autonomous, Multi-Sensor Scanning and 3D Model Generation for Ship Configuration Management

Professor:
John Gilbert,
Kevin Schroeder,
Geoffrey Kerr,
Alan Brown,
Taylan Topcu

Students:
- **Undergraduate:** 2
- **Master's:** 2
- **PhD:** 1

Virginia Polytechnic Institute and State University

This project seeks to autonomously generate 3D digital models of large, complex structures through a combination of drone-based multi-sensor scanning, machine learning, and the integration of pre-existing 3D models. Specifically, the proposed effort will use sensor data fusion, computer vision, and machine learning to auto-label LiDAR point-cloud data collected from drone-based scans. Additionally, the proposed effort will integrate pre-existing 3D computer aided design (CAD) models to inform and automate the creation of "as-built" digital reconstructions. The scanning and 3D modeling efforts will be united through annual case-studies aimed at assessing system performance.

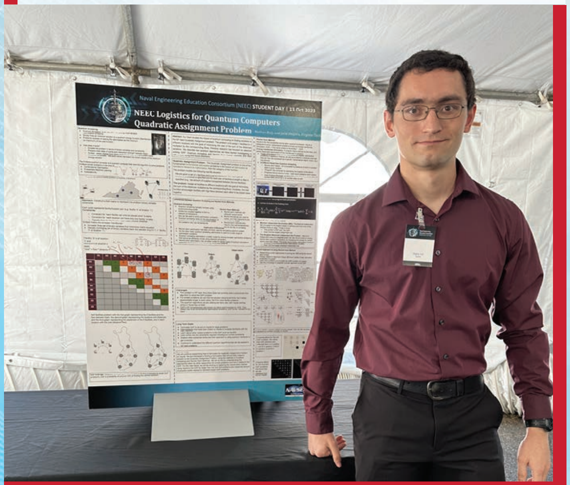
The proposed work leverages Virginia Tech National Security Institute (VTNSI's) prior experience with multi-sensor (camera+LiDAR) drone platforms, computer vision, and machine learning. This effort will lead to a dramatic reduction in man-hours required to generate quality 3D digital reconstructions of large structures and facilitate future Navy digital transformation efforts.

Image courtesy of Defense Visual Information Distribution Service (www.dvidshub.net).

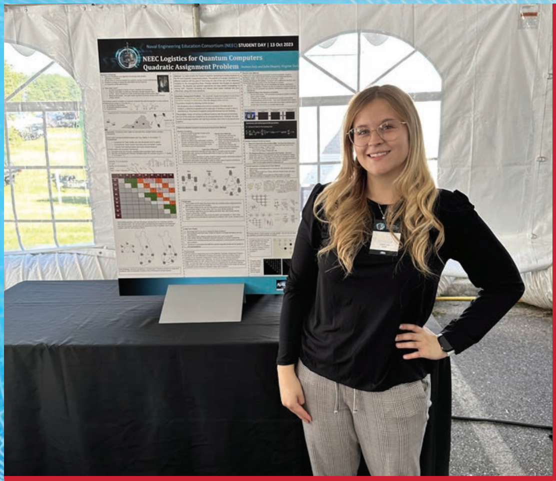
Logistics Algorithm Development for Quantum Computers (LAD-QC)

Professor:
Thomas Krauss

Students:
- Master's: 2



Graduate student attending NEEC Student Day at the Naval Surface Warfare Center Dahlgren Division.

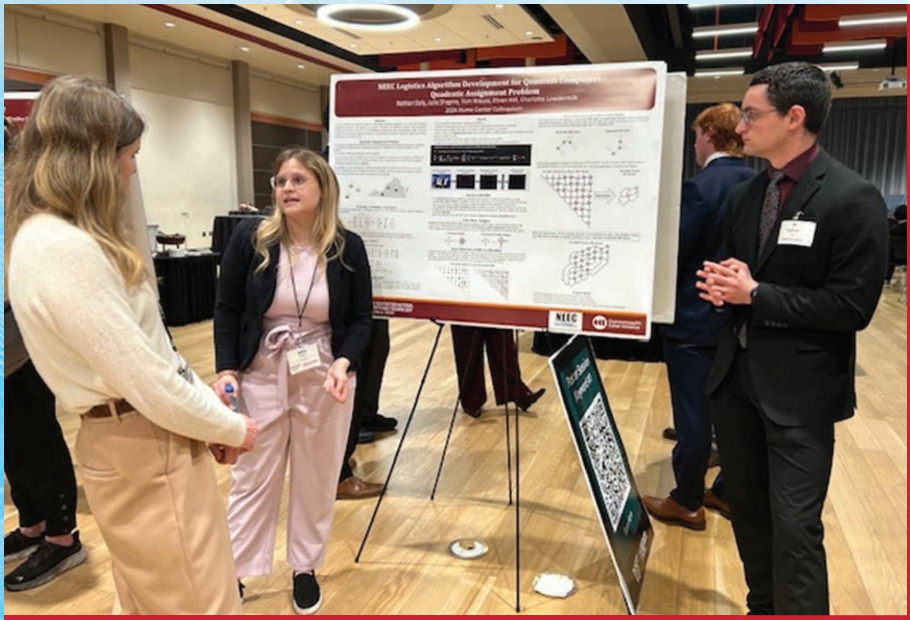


Graduate student attending NEEC Student Day at the Naval Surface Warfare Center Dahlgren Division.

Virginia Polytechnic Institute and State University

The production, storage, and/or distribution of materiel among sites, which can be modeled by the Quadratic Assignment Problem (QAP), is an important fundamental problem for logistics. A wide variety of practical problems in design, planning, and management can be described in this form. For example, given a set of facilities and a set of locations, each pair of locations is assigned a distance, and each pair of facilities is assigned a "weight" or "flow" of materiel (e.g., the number of supplies transported between the two facilities). The problem is to assign each facility to a unique location with the goal of minimizing the sum of all location distances multiplied by the flows of the facilities at those locations. This is an NP-hard problem and is one of the few such problems known to be difficult for classical computers in practice, even for relatively small instances. Since algorithms for producing optimal solutions to such problems are computationally infeasible for all but small problems, heuristic techniques are usually used for the solution of real practical problems.

The goal of the Logistics Algorithm Development for Quantum Computers project is to demonstrate the potential efficacy of quantum algorithms for the Quadratic Assignment Problem by building on the existing, demonstrated theoretical quantum algorithms for route optimization and to develop QAP quantum formulations suitable for execution on quantum hardware. The proof-of-concept quantum formulations will demonstrate a reduction in complexity for specific cases of the QAP. Multiple architectures of quantum computing will be evaluated including quantum annealing, gate based, and analog (e.g., neutral ion) allowing for understanding of the applicability of the architecture to the logistics problem. This will also provide students with direct exposure to problems of national interest, access to quantum computing hardware including the neutral atom and quantum annealing machines, and develop real-world experience in quantum application development. These programs will be geared toward enhancing students' essential skills to enter the national security workforce by establishing multiple student teams whose tasks are to develop novel research that solves a specific naval need.

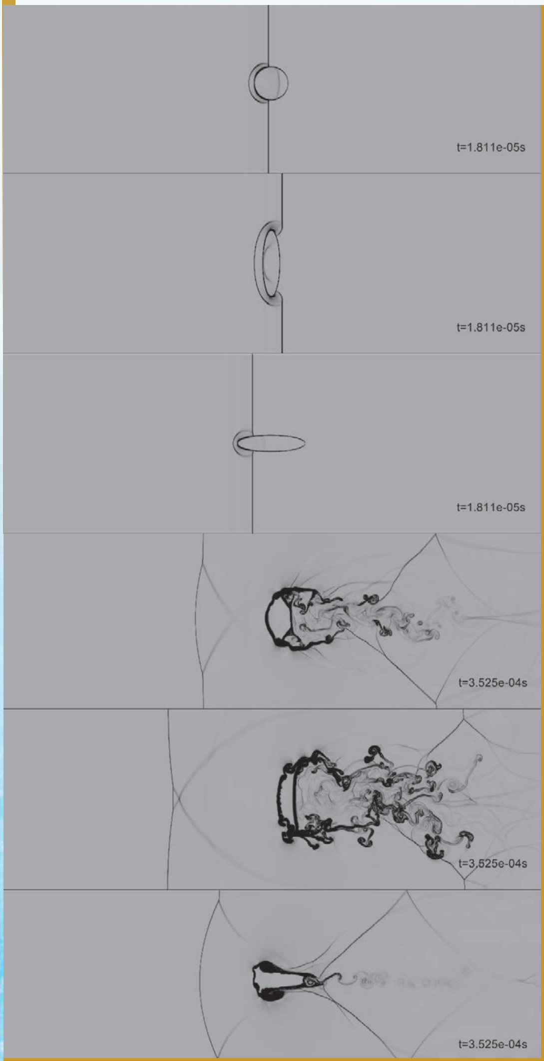


Graduate students presenting during the poster session at the 11th Annual Hume Center Colloquium.

Fundamental Studies on Liquid Droplet Atomization and Vaporization in Shock-Laden Environments Relevant to Compact Liquid-Fueled High-Speed Propulsion Engines

Professor:
Prashant Khare

Students:
- **PhD:** 2

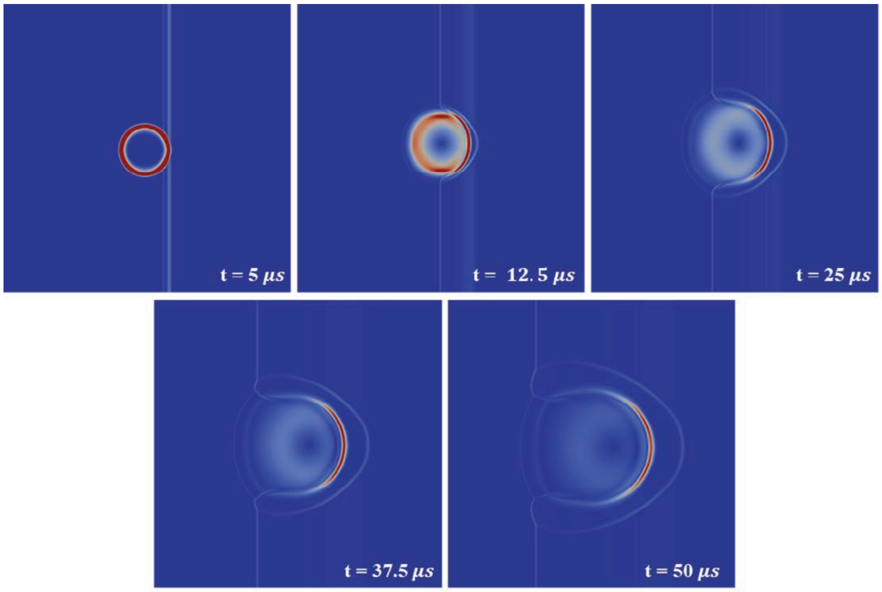


Effect of cross section on shock liquid column interactions.

University of Cincinnati

The use of liquid fuels is necessary to significantly increase the range and flight duration of future air-breathing high-speed aircraft, not only because of their higher energy density but also because of their potential use for regenerative cooling. As opposed to propulsion systems operating with gaseous fuels, where the combustion phenomenon is limited by mixing, in liquid-fueled combustors, while molecular transport and mixing are important, two additional processes—fragmentation and vaporization of droplets—are usually the rate-controlling processes. However, the available scientific literature does not lend itself to providing this knowledge and, therefore, severely limits our ability to accurately analyze and design these future systems. Therefore, in this three-year project, we are investigating the origin and spatiotemporal evolution of hydrodynamic instabilities of isolated and groups of non-vaporizing and vaporizing liquid fuel droplets as they interact with shock waves traveling at a wide range of Mach numbers. To undertake this research, we are using a fully compressible Eulerian-Eulerian diffuse interface volume-of-fluid-based interface capturing methodology with an explicit treatment of surface tension, viscous, and vaporization effects. Thus, by accurately modeling the physics under consideration and resolving all the relevant spatial and temporal scales in the gaseous and liquid phases, and at their interface, we will substantially improve the state of knowledge.

The expected scientific contributions from this program include the establishment of predictive theories of fragmenting and vaporizing fuel droplets as they interact with supersonic flows and shock waves. These scientific outcomes will significantly contribute to the design and development of next-generation air-breathing liquid-fueled RDE and scramjet engines that are required to meet and exceed the range and operational needs of the Navy's supersonic/hypersonic aircraft and munition systems. Additionally, this project will develop the future naval science and technology workforce by engaging and training students in areas vital to national security.



Vaporization and fragmentation of a dodecane droplet as it interacts with a shock wave traveling with a Mach number of 6.5.

Direct Ink Write 3D Printing Microporous Nitramines

Professor:
Veronica Eliasson

Students:
- **Undergraduate:** 2
- **PhD:** 3

Colorado School of Mines

Legacy composite solid propellants contain strategically placed perforations to modify the burn regime of the propellant system. The addition of perforations can become very complex, especially when the thrust profile of the solid propellant needs to be changed as the propellant burns. While there is significant research on the effect of propellant grain structure on the expected thrust output, the manufacturability of more complex grain structures requires very precise techniques. Additionally, legacy propellants are costly to manufacture due to the need to machine a mold, cast the propellant, and then potentially machine further as a final touch-up.

An alternative to traditional cast-cure propellants is provided by propellants manufactured using an additive manufacturing technique called direct ink write (DIW) 3D printing. DIW 3D printing is a novel approach to manufacturing solid propellants, mostly due to its simpler one-step process. In DIW 3D printing, solids-loaded, viscous, polymers are dispensed through a nozzle and placed onto a print surface.

Subsequent layers may then be added to the initial layer, layer by layer, until a three-dimensional structure is formed. DIW 3D printing allows for complex propellant grains to be created without the need to demold or machine a cured propellant. This increases safety and manufacturability as compared to traditional cast-cure solid propellants.

More complex geometries are possible with DIW 3D printing than with traditional cast-cure propellants. DIW 3D printing allows the manufacture of novel grain structures at a layer-by-layer granularity, meaning that the cross section can change for each layer, increasing the complexity of the overall print. This also allows the solids loading to be varied depending on the layer, which is an added way to control the thrust profile of the overall printed solid propellant. Different formulations, such as energetic resins coupled with explosives, such as HMX, will be tested to determine the formulation with the most favorable mechanical properties for DIW 3D printing. Spray drying HMX may also help to tune the formulation, making HMX less sensitive and have a more consistent crystal size. It is expected that a polymer system close to its glass transition would maximize the printability using DIW 3D printing.


Undergraduate student working in the chemistry lab.

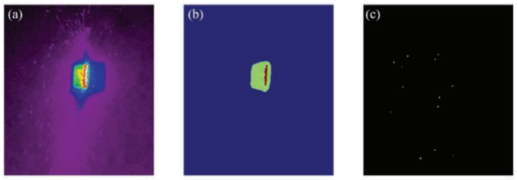
PhD student working in the chemistry lab.

Undergraduate student machining parts.

Enabling Real-Time Flaw Detection in Laser Powder Bed Fusion Using In-Situ Infrared Monitoring by Integrating Image Processing, Machine Learning, and Hardware/Software Co-Design

Professor:
Albert C. To,
Peipei Zhou

Students:
- **Undergraduate:** 2
- **PhD:** 1



Spatter detection from the IR monitoring: (a) raw IR data while scanning, (b) scanning filter algorithm with green representing areas previously scanned and red representing the current melt pool area, (c) further spattering filtering yields an image with easily identifiable spatters.

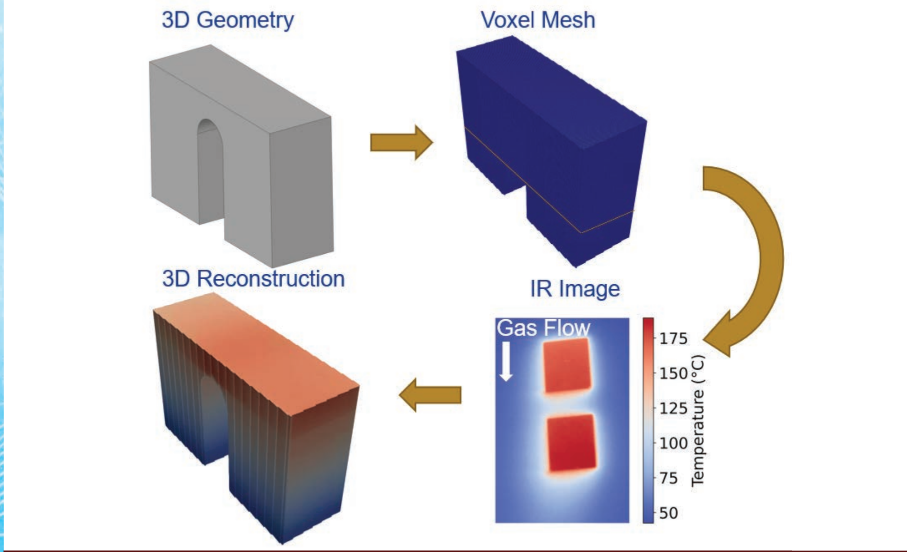
PhD candidate setting up the IR camera on the EOS M290 DMLS machine

University of Pittsburgh

The laser powder bed fusion (LPBF) process can incur defects due to melt pool instabilities, spattering, temperature increase, and powder spread anomalies. Since most of these defects are difficult to predict using computer simulations alone, it is beneficial to employ in-situ monitoring to detect these defects using sensing devices such as an infrared (IR) camera. In-situ monitoring has been previously proposed; however, existing algorithms for processing data collection are too inefficient in real time.

The goal of this project is to address this critical issue by developing novel image processing and machine learning (ML) algorithms in combination with hardware/software co-design, to enable real-time processing of end-to-end data analysis and IR camera monitoring. Specifically, the image processing and ML algorithms will be developed to predict local porosity and location of large defects given the IR data. The project team will also design domain-specific hardware accelerators (DSA) and implement these algorithms on AMD/Xilinx VCK190 Versal Adaptive Compute Acceleration Platforms (ACAP) to process IR images collected during LPBF processing and enable real-time defect detection in a layerwise manner.

This project addresses one of the top priorities for the quality assurance (QA) of LPBF produced naval components and use of post-build non-destructive evaluation (NDE). The current QA method for critical LPBF processed naval components requires extensive ex-situ NDE to detect porous defects and flaws, such as micro-CT, which is expensive and time-consuming. The proposed real-time in-situ defect detection method will significantly reduce the number of ex-situ NDE tests needed to inspect LPBF components, thereby reducing inspection time and costs by 1 to 2 orders of magnitude. In longer term, the proposed real-time technology will potentially enable "detect and repair" and save numerous defective components from becoming waste, resulting in substantial savings in material and manufacturing costs. Therefore, the proposed technology is expected to significantly enhance the Navy's ability to produce legacy parts in small quantity, replace broken parts in the battlefield, and fabricate high-value complex parts (e.g., compact heat exchangers in submarines) reliably at much lower costs.



Proposed IR camera mesh projection workflow for 3D geometry of an arch structure: (step 1) volexize the geometry, (step 2) process the raw IR data to obtain certain feature (e.g., interpass temperature), and (step 3) map the feature onto the voxel mesh.

Artificial Intelligence Models for Predicting Supply Chain Failures and Their Impacts

Professor:
Hugh Medal,
Mike Sherwin

Students:
- **Undergraduate:** 5
- **PhD:** 1

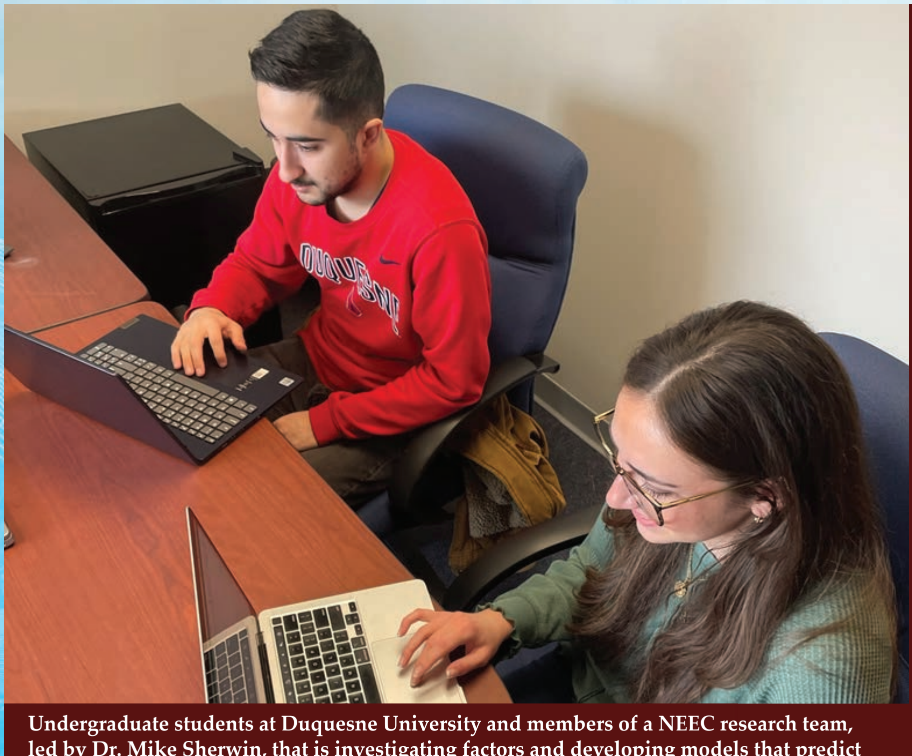
University of Tennessee, Knoxville

Diminishing manufacturing sources and material shortages (DMSMS) present significant challenges to maintaining systems with a long sustainment life. This problem is especially relevant to the US Navy, where systems such as submarines have a sustainment life of forty years or more.

This project seeks to develop quantitative tools, in particular machine learning and optimization, to help mitigate DMSMS issues, with a focus on part obsolescence. Part obsolescence occurs when parts become unavailable due to causes such as suppliers going out of business, suppliers being acquired by a larger company, and changes in environmental and safety regulations. In this project, we plan to develop quantitative tools to support several different phases of DMSMS management.

For the prediction phase, we are developing machine learning tools for predicting when a part becomes obsolete, using factors related to parts as well as factors related to suppliers. We aim to utilize data sets that are part of the existing Obsolescence Management Information System (OMIS) in combination with new data sets to build our prediction model. These tools are expected to provide better predictions of when parts will become obsolete, enabling the US Navy (USN) to employ a more proactive approach to managing obsolescence, likely resulting in significant cost savings.

For the mitigation phase, we are developing tools to help decision-makers make better decisions related to design refresh planning. Specifically, we are developing a model to help determine how often a system should undergo a design refresh, which parts should be included in each refresh, and when mitigation options, such as a lifetime buy, should be employed. These tools will help USN decision-makers quickly determine the best course of action for mitigating current or upcoming obsolescence events, likely resulting in significant cost savings.



Undergraduate students at Duquesne University and members of a NEEC research team, led by Dr. Mike Sherwin, that is investigating factors and developing models that predict supplier obsolescence. Students are a junior majoring in Computer Science and a junior majoring in Supply Chain Management.

NUWC Keyport

Sentiment and Topic Analysis for Reliable Supply (STARS)

Professor:
Maice Costa

Students:
- Undergraduate: 1

Virginia Polytechnic Institute and State University

Logistics and repair centers can greatly benefit from data analytics to expedite the processing of large volumes of collected data related to products and suppliers. Some level of automation can improve efficiency in the acquisition and maintenance processes by reducing the cognitive burden imposed on human agents to analyze the collected data. Data related to products and suppliers is often in narrative format, so the automation process requires the integration of Natural Language Processing tools. In particular, sentiment and topic analysis can be used to extract subjective information from text. With these tools, it is possible to analyze text describing past experience with a product or vendor to assess the level of satisfaction and identify potential issues and risks.

Project objectives are to use Natural Language Processing to expedite analysis of text in product and supplier reviews and to use sentiment and topic analysis tools to extract subjective information from text. We utilize publicly available datasets with reviews (movies, products, services) to test the proposed algorithms. The sentiment analysis classifies text as positive/negative, and we also perform a multi-class classification that is compared to the star ratings associated to the reviews. We have tested lexicon (list of words) and deep learning classifiers, with the latter providing better performance at the cost of higher computational complexity. We are currently working to automate topic analysis to identify common complaints in the reviews.

Image courtesy of Defense Visual Information Distribution Service (www.dvidshub.net).

NUWC Keyport

Investigation of a Human-Assisted Multi-Robot System for Inspection of Hazardous Confined Spaces

Professor:
Ashis G. Banerjee,
Santosh Devasia

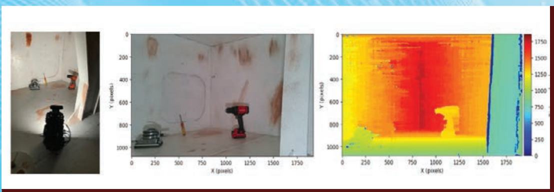
Students:
- **Undergraduate:** 9
- **Master's:** 2
- **PhD:** 1

University of Washington

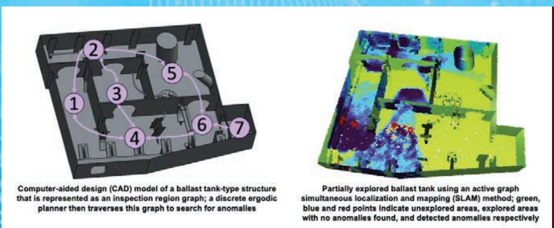
Most large marine vessels are complex systems that operate in extreme open-ocean environments. As a result, they require significant cost and effort to maintain, especially as the vessels age. Some of the most challenging maintenance tasks occur inside large confined spaces inside the vessels. In particular, the vessels contain numerous "gray-water" tanks that can be fully or partially filled with seawater when the vessels are underway. The tanks provide critical access to much of the machinery on the vessels but are difficult and dangerous spaces for humans to access. Given these hazards, there is a lot of potential for the use of robots to perform many of these tasks.

However, there are two major challenges in this regard. First, the interiors of these confined spaces are often discolored, poorly illuminated, and unstructured, all of which cause issues for traditional vision-based localization, mapping, and navigation approaches. Second, the spaces are often irregularly shaped and cluttered with structural elements. Hence, it is difficult even for a robot to move inside the tank and access all the components, rendering robust locomotion and smart exploration nontrivial. The current tethered solutions have been unwieldy to maneuver, and the expensive custom-designed robots with a large number of actuated joints have not been found to be reliable. While drones can be used, they tend to have limited flight times and may not be well suited for close-up inspection tasks.

Therefore, instead of using a single customized robot, we are building a low-cost, decentralized heterogeneous robot network that will be deployed with human assistance. Inter-robot communication and communication between the robots and remote human supervisor(s) are expected to be unreliable and will be limited to key information sharing. Noting that human supervisors will have prior knowledge of the inspection tasks, the networked system will primarily solicit their assistance in positioning the robots initially at suitable locations. Once positioned, the robots will automatically navigate and explore their neighboring regions. Consequently, the humans will only need to intervene under two circumstances: a) reposition the robots if they have finished their allocated tasks, and b) assess the significance of the anomalies identified by the robots.



An external view of a customized ground robot examining a section inside the scaled-down water tank (left), color image taken by the robot camera showing rust patches (center) and the corresponding depth image by the same camera clearly indicating an FOD (right).



Active exploration of a confined space by an autonomous ground robot for detecting anomalies such as foreign object debris (FODs), corroded structures, and damaged components.

Senior capstone project team working on testing a low-cost robotic inspection system for a scaled-down tank in a dry-docked vessel.

NUWC Keyport

Mechanical Obsolescence Management: Risk-Based Analysis and Prediction

Professor:
Christina Mastrangelo

Students:
- **Undergraduate:** 5
- **PhD:** 1

University of Washington

Obsolescence occurs when a given part is no longer procurable. This causes problems for organizations, particularly those that manage long-lived systems. When a part in these systems experiences obsolescence, a plan must be developed to keep the system operable. In order to give decision-makers more time to develop plans to adapt to obsolescence, the projects are working toward a proactive strategy to better manage obsolescence events at the part level and the effects at the system level.

Project 1:
The goal of this project is a more proactive ... a more proactive obsolescence management achieved by looking at the component lifecycle and combining that with predictive modeling for hardware or mechanical parts. The result is potential new insights or features that will allow obsolescence management to continue to move from a reactive to a proactive approach, addressing problems before they occur. In this reporting period, the team has collected and analyzed data on a variety of mechanical part types and tested the predictive analytics developed for COTS and electronic parts on this part type for implementation into NUWC Keyport's Obsolescence Management Information System (OMIS™). The team also developed, tested, and implemented an approximate confidence interval for the likelihood of obsolescence prediction.

Project 2:
While the prior work focused on utilizing predictive analytics for risk at the part level, this project has two focuses: 1) taking a broader view of the problem to develop predictive analytics for system-level obsolescence and 2) applying natural language processing algorithms to text fields in OMIS™ to improve the case management capabilities, which will improve the timeliness and quality of case response to the NAVSEA program offices. The first focus will develop analytical methods for system level unavailability. This will allow us to understand how parts interact within a system, how unavailability propagates in a system, and how to weigh the importance of different parts becoming unavailable. This enables one to identify the most important unavailability (aka supply chain) risks and thus allocate resources to the parts whose unavailability creates the largest risk to the system.

Mechanical Obsolescence Management: Risk-Based Analysis and Prediction team.

Mechanical Obsolescence Management: Risk-Based Analysis and Prediction team.

Towards the Design of Polymers for Additive Manufacturing with Resistance to Marine Environment Degradation: A Data Science Approach

Professor:
Navid Zobeiry,
Dwayne Arola

Students:
- **Undergraduate:** 5
- **Master's:** 1
- **PhD:** 1

University of Washington

UNIVERSITY of WASHINGTON

Additive manufacturing (AM) is revolutionizing the design and manufacturing process for the development of components involving nearly all classes of materials. Polymer AM processes could ignite transformational changes in the development of next-generation naval structures, including autonomous and unmanned underwater vehicles. However, the exposure of polymer structures to marine environments poses concern about their durability. In this three-year program, the team is pursuing a combination of experimental and data-driven tasks.

The experimental efforts are focused on evaluating the durability of selected neat thermoplastics and thermoplastic composites after AM processing and prolonged marine exposure. Specifically, the team is evaluating the performance of Ultem 9085 and Ultem 1010 structures produced by fused filament fabrication (FFF). The team is also pursuing complementary activities concerning the printabilty of both experimental and commercial composite filaments by FFF with continuous fibers. The key concerns in this effort are the quality and reliability of the printed material, as well as the degradation within marine environments. The current efforts are foundational as the next steps are to advance the capability for printing these materials using robotic systems for manufacturing composite structures and characterize the resulting structural integrity of printed forms. Potential approaches include the scalable composite robotic additive manufacturing systems and using advanced fiber placement of composite tape materials.

The data-driven activities start with the development of a comprehensive database from datasets in the public domain composed of detailed structure, chemical, and physical properties for monomers and polymers to support data science approaches to materials exploration and development. The team will analyze and predict marine degradation using molecular dynamics simulations for selected polymers according to an accelerated degradation protocol. Then it will be necessary to validate this approach to materials analysis and prediction of degradation by using physical testing and complementary analyses.

University of Washington student standing next to his poster focused on the degradation of 3D printed polyphenylene sulfide (a polymer) that was presented at the Materials Science and Engineering "Industry Days".

Students from University of Washington and Carnegie Mellon University, respectively, conducting mechanical testing of the aged samples.

Undergraduate in Materials Science and Engineering student, extracting samples from the marine aging bath

NUWC Keyport

Secure Communication System Using Magnetic Induction Field In and Across Different Media

Professor:
Murari Kejariwal

Students:
- **Undergraduate:** 9
- **Master's:** 2
- **PhD:** 1

Students on NEEC Project during 2023-24

Washington State University

Magnetic Induction (MI) communication is accomplished by modulating a magnetic field with the data using a small magnetic coil. Another coil, in which a current is induced, is placed in the modulated varying magnetic field. MI has a negligible propagation delay and a predictable stable channel. However, the range is very limited. Normally, the range is 10–100 meters with a frequency in MHz. The salient advantage of MI is that it can be operated in a stealth mode and also across mediums such air and water. This makes it a very useful means of communication for the Navy to stealthily control a fleet of Unmanned Underwater Vehicles (UUVs).

In near field communication it can be very effective due to the small-size transmitter and receiver coils. It can be operated at low power. The work done this year is the continuation of work done in previous years where the students established the viability of this MI technique. There were three main objectives this academic year. They are:

1. Increasing the range: The present system is redesigned to increase the range to 500 cm and beyond from previous 100cm range. The range is increased by using a higher driver voltage, redesigning the transmitter and receiver coils.
2. The next phase consists of determining the right frequency for communication. A 200kHz signal frequency satisfied multiple criteria.
3. The third phase was to find the optimum size of the coil, number of turns, size of the wire. Keeping many factors in perspective, the coil used consists of 30 turns with 24-gauge copper wire. Unidirectional and omnidirectional coils are designed and tested as shown in the figure.

The communication and control system is tested by using move forward, left, right, and back commands for a UUV. The commands are coded using Raspberry Pico, low-power microcontroller using a frequency modulation scheme. On the receiver, a phase-locked loop circuit along with Pico is used for decoding. The figure shows the experimental setup used for verification of the design in saltwater and in air.

Student adjusting the orientation of Magnetic Induction Coils.

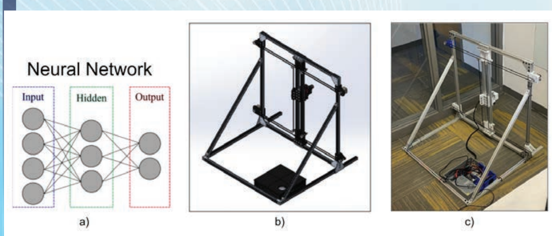
Students working on MI communication in saltwater tank. The communication coils are at two ends of the tank.

NUWC Newport

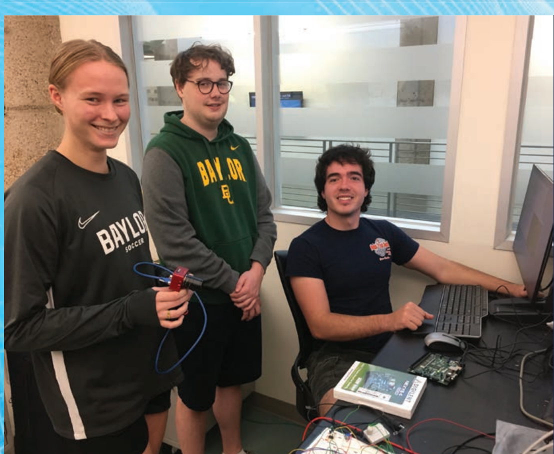
Sensing and Computational Methods Enabling Edge Computing for Autonomous Platforms

Professor:
Scott Koziol

Students:
- **Undergraduate:** 4
- **Master's:** 3
- **PhD:** 1



WACO, TX – Selected components of the Baylor NEEC project: a) merging sensors with a Neural Network b) computer aided design drawing: rear view of the prototype H-Bot design for the Baylor University NEEC Senior Design Project's Camera Shaker gantry system: c) constructed prototype of the design in (b).



WACO, TX - Baylor University students pose in the Neuromorphic & Robotic Systems research lab. Their Baylor faculty advisor for the project is Dr. Scott Koziol, and the NUWC Division Newport mentors are Dr. John DiCecco and Dr. Eugene Chabot.

Baylor University

The objective of this work is to use novel sensor processing techniques to provide improved autonomous robot capabilities by changing the way onboard computation is performed. The scope of this project is circuit and algorithm co-development, computer simulation, and circuit/sensor hardware experiments. We will assess the performance of the proposed bio-inspired edge computing method for sensor data output. The proposed method's computation capabilities will be compared to standard digital implementation methods (e.g., image processing, neural networks, position localization).

The system-level problem being addressed is to explore the intersection of sensors and computing for optimal architectures. The anticipated outcome is that, by understanding the sensor format and computation, we will be able to define better resource-optimized architectures. This will provide better onboard computation systems for small autonomous robots performing missions. This is important because onboard computation is limited due to size and power constraints. Potential naval relevant applications are for integration into multi-vehicle autonomous systems to improve navigation, acoustic localization, or underwater sound tracking in challenging environments. The broad technical approach is to develop nontraditional computing, such as neuromorphic computation and sensing architectures.

A potential impact is improved system robustness to noise. This architecture is efficient for making decisions on small amounts of information and incrementally refining them. An anticipated outcome is that this provides a framework for integrating progressive observations to improve the solution with an efficient architecture. This NEEC project focuses on the intersection of sensing and computing.

WACO, TX - Baylor University engineering students pose at their Senior Design project final presentation. Their Baylor faculty sponsor for the project is Dr. Scott Koziol. The spring 2023 Senior Design team created a test instrument and control software that supports the Baylor NEEC project. The gantry system was designed to systematically move an Event Camera device. The purpose of this test instrument is to create training and test data for the NEEC project.

NUWC Newport

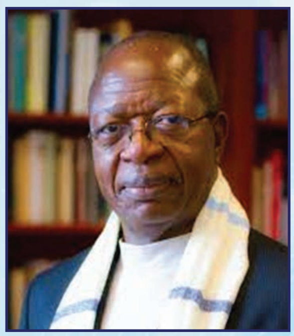
Howard University

Advanced Mathematical and Computational Methods for Probability Densities Evaluations and Information Measurements Involving AI/Ml

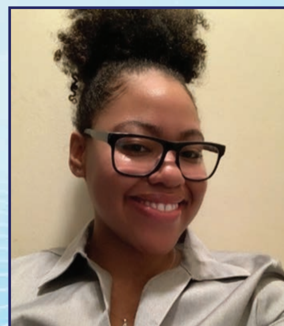
Professor:
Bourama Toni

Students:
- PhD: 1

Our project, which is PhD-grade, develops and uses advanced mathematical and computational tools to provide effective techniques to evaluate probability densities (weighted Gaussian and non-Gaussian) of multivariate random transformations involving dimensional change. The first phase, near completion, is developing new multidimensional infinite integral identities, harnessing the power of the math software Mathematica. These identities relate, in elegant compact formulas, to special functions in statistical and probability theories such as gamma, beta, Bessel, hypergeometric, and Riemann-zeta functions. In the second phase, our research contributes in a foundational way to the ONR Pathfinder project: to develop a methodology, beyond Kullback et al. discrimination information, for extracting knowledge/reusable prescription, e.g., from streaming sampled measurements carried out by passive phased arrays of acoustic sensors with a focus: data and information models, flow noise mitigation, and low frequency spherical array processing. Our purpose is a topological data model interacting dynamically with an ad hoc information model for AI/ML application.



Dr. Bourama Toni.



NEEC PhD Student.

Seeking and finding bio-inspired data and information models…. in the Louisiana Bayou.

NUWC Newport

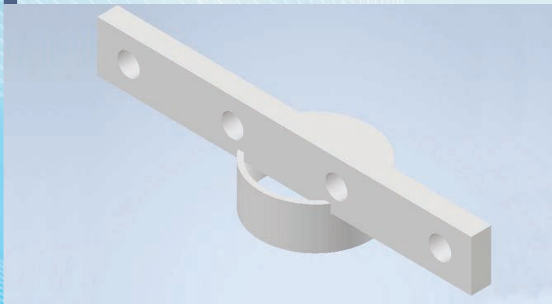
University of Massachusetts Dartmouth

An Adaptive Deep Learning Architecture with FPGA Acceleration for Continuously Monitoring and Characterizing Operations and Promptly Reconfiguring SDR in Spectrum Contested Environments

Professor:
Ruolin Zhou

Students:
- Undergraduate: 2
- PhD: 1

The electromagnetic spectrum (EMS) ranges from radio waves, microwaves, visible light, to X-rays, and it supports Department of Defense (DoD) air, land, sea, space, and cyberspace spectrum-dependent wireless systems and applications. Due to the technology evolution as well as 5G and beyond, which provides high capacity, faster speeds, world-wide connectivity, terrestrial and non-terrestrial communications, it has been harder for the warfighters to have freedom of action within the EMS to be successfully operational in congested, contested, and constrained EMS environments globally. The Department has developed the “2020 Department of Defense Electromagnetic Spectrum Superiority Strategy” to ensure that the US military maintains its ability to operate in the EMS and retrieve the “freedom of maneuver” in future by dynamically accessing the EMS. A key barrier to advancing the “freedom of maneuver” in the EMS is the lack of efficient and effective methods to sense the EMS and learn surrounding operations and signals in dynamic EMS environments. Therefore, the goal of the project is to continuously monitor and characterize operations and signals in dynamically congested, contested, and constrained EMS environments to better meet DoD’s command, control, and communication needs on their battlefields and beyond as well as Navy’s needs on EMS-dependent applications and systems. We designed a software-defined radio testbed with a four-element antenna array enabled by two universal software radio peripherals (USRP) X310 synchronized by an OctoClock-G. We conducted tests and implemented various angle-of-arrival estimation techniques, including multiple signal classification (MUSIC), estimation of signal parameters via rotational invariance techniques (ESPRIT), and machine learning using artificial neural networks (ANNs) and convolutional neural networks (CNNs). The performance of these techniques is compared using both synthetic signals and over-the-air test scenarios with in-phase and quadrature (I/Q) samples as well as covariance matrices of I/Q as inputs. Our findings revealed that MUSIC outperformed ESPRIT in terms of the mean absolute error (MAE) in synthetic scenarios. For over-the-air scenarios, a CNN based on a residual network architecture exhibited the best MAE performance, albeit with slower execution speed. A basic CNN on the covariance matrix and an ANN on I/Q samples demonstrated the fastest execution time.


3D-printed antenna array holder of the software defined radio (SDR) based angle-of-arrival (AoA) testbed


SDR-based AoA testbed


NEEC students

Deep Evolutionary Reinforcement Learning for Integrated Sensor Design, Dynamics, and Acoustic Target Recognition

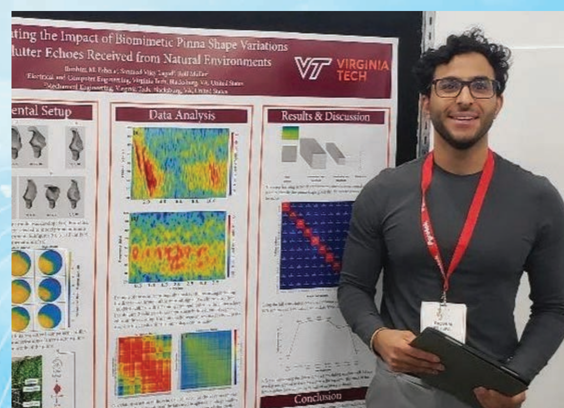
Professor:
Rolf Mueller

Students:
- **Undergraduate:** 41
- **PhD:** 1

Virginia Polytechnic Institute and State University

Small, low-cost underwater vehicles that can accomplish a mission autonomously are of great importance to future Navy operations. These vehicles should be able to operate in shallow-water environments that are difficult because underwater navigation relies on sonar, and the proximity to the sea floor or other underwater objects produces large amounts of sonar echoes as well as acoustic reverberation. In addition, the environmental conditions can vary a lot around the world; and hence, a method that can automatically design sonar systems for different uses and areas of operation would be highly desirable. This NEEC research seeks to design a miniature sonar that is inspired by the biological sonar systems found in certain species of bats that are able to fly through dense vegetation. These bats diffract their outgoing biosonar pulses with little megaphones ("noseleaves") and the returning echoes with their outer ears. Bat biosonar has a unique dynamics where the noseleaves and ears are deformed by a large number of muscles associated with each structure. To replicate the capabilities of bat biosonar in a technical design, a process will be used that mimics evolution, and individual learning will be implemented. In the process, the layout of the actuators that deform the baffles will be optimized using an evolutionary algorithm, and each actuator layout will be trained by a deep-learning process similar to the one Google has used to beat human Go champions. The outcome of this effort will be a miniature biomimetic sonar that can determine its location in a natural environment from the analysis of echoes and thus is no longer dependent on GPS. This will enable small underwater vehicles that do not need to surface to operate a GPS receiver. Furthermore, the evolutionary AI design process can be repeated to create capable sonars that are optimized for specific missions.

Working on a 3D printed part for the bat robot.



Award-winning poster at the Meeting of the Acoustical Society in Sydney.

Field testing the biomimetic bat robot on Borneo.


Meeting of the bat robot senior design team.

A Machine-Learning Enabled Approach for Real-Time Plume Estimation with a Network of Autonomous Underwater Vehicles

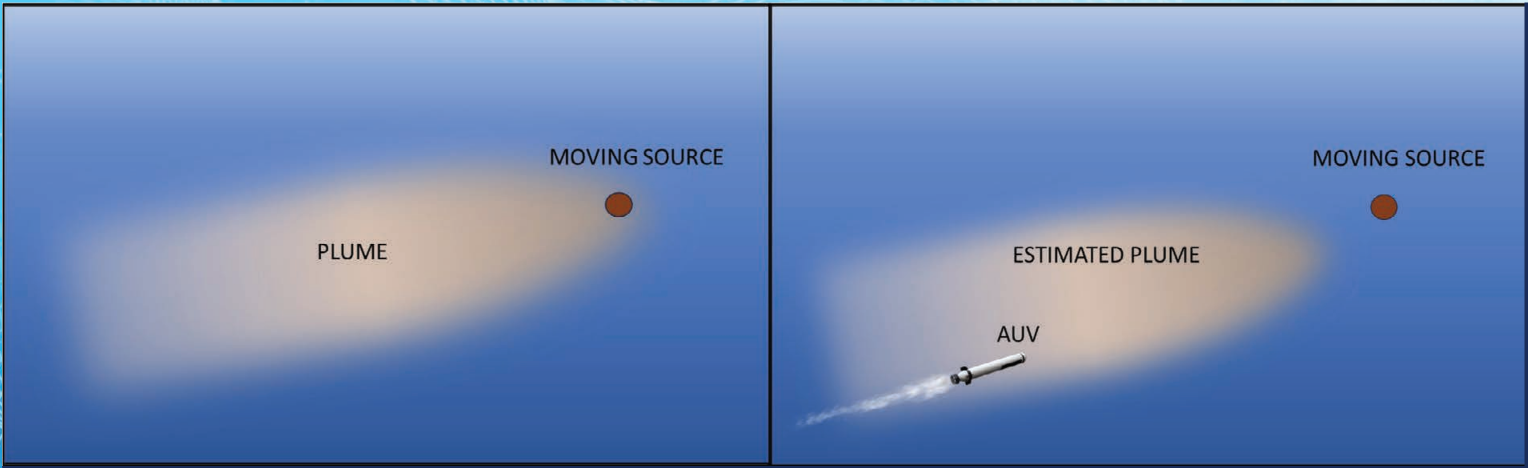
Professor:
Nikolaos A Gatsonis, PI
Michael A. Demetriou (Co-PI)

Students:
- MS/PhD: 1

Worcester Polytechnic Institute

The research project at Worcester Polytechnic Institute (WPI) develops a highly-dynamical system estimation approach enabled by machine learning. The highly-dynamical system considered consists of a moving underwater unknown source that releases a liquid or gas, resulting in a spatiotemporally varying plume where a single autonomous underwater vehicle (AUV) or a network of AUVs performs plume estimation. The objective of the project is to develop an approach that guides and optimally repositions the AUVs, so that the onboard estimator provides in real time a prediction of the plume concentration, source strength, and localization.

The project advances the state of the art. The estimation approach is physics-inspired and incorporates the plume dispersion modeled by the 3D advection diffusion equation, the motion of the unknown source modeled as an exosystem, the motion of the guided AUVs modeled by dynamical equations, and the concentration sensor modeled with bandwidth and noise. The estimation approach is data-driven, because through adaptive sampling in the plume, the burden of processing "big data" is replaced by significantly reduced "smart data" taken by the limited number of AUVs. The estimation approach is also machine-learning enabled, utilizing a physics-informed scheme with an estimator implemented with advanced computational methods bridging the multiple scales of the highly-dynamical system and is real-time executable onboard AUVs. The estimation approach provides in real time human interpreted results that can lead to effective decision making. The project engages supported graduate and unsupported undergraduate students, contributing to their education for potential future careers in the DoD.



(Left) Plume formation from a moving underwater source that releases a gas or liquid in the environment. (Right) An AUV estimates the plume in real time.

NSWC Panama City

Active and Cooperative Terrain-Aided Navigation Using Inverted-Ultra-Short Baseline (USBL)

Professor:
Joshua Mangelson

Students:
- **Undergraduate:** 6
- **PhD:** 2

Brigham Young University

The feature-poor environment of the underwater domain makes it difficult for low-cost unmanned underwater vehicles (UUVs) to maintain localization accuracy when traveling large distances under GPS-denied conditions. Terrain-aided navigation (TAN) attempts to correct navigation drift by comparing observed depth measurements to a prior bathymetry map. However, these techniques depend on observation of changes in bathymetry. If the bathymetry of the environment is mostly constant and the UUV fails to travel over the points that do vary, then TAN will fail to correct navigation drift. Teams of agents performing cooperative localization have the potential to overcome these problems by increasing the search space observed by the individual agents. If an accurate relative localization is maintained between the agents, then a useful observation by any one of the UUVs will result in improved localization for the entire group. Moreover, by optimizing the trajectories of each of the vehicles, we can seek to maximize the likelihood that useful changes in bathymetry will be observed by the coordinating agents, resulting in even further increases in localization accuracy. Ultimately, depending on the bathymetry of the environment, it is possible that an optimal trajectory for the team could be found that would ensure that the drift could be entirely corrected by using these techniques.

In this project, we seek to investigate the various problems that need to be addressed to enable cooperative terrain-aided navigation at large scales. In particular, we propose to investigate: i) Communication-Constrained Cooperative Inverted-USBL Localization, ii) Cooperative Terrain-Aided Navigation, and iii) Optimal Planning for Active Cooperative TAN. Expected results include publications in tier-one robotics venues and demonstrated evaluation of the proposed algorithms via real-world field trials.

NEEC Students with a BYU-build UUV based on the NSWC PCD-designed Deployable-Reusable Underwater Vehicle (DREW-UV).

NEEC student in the lab.

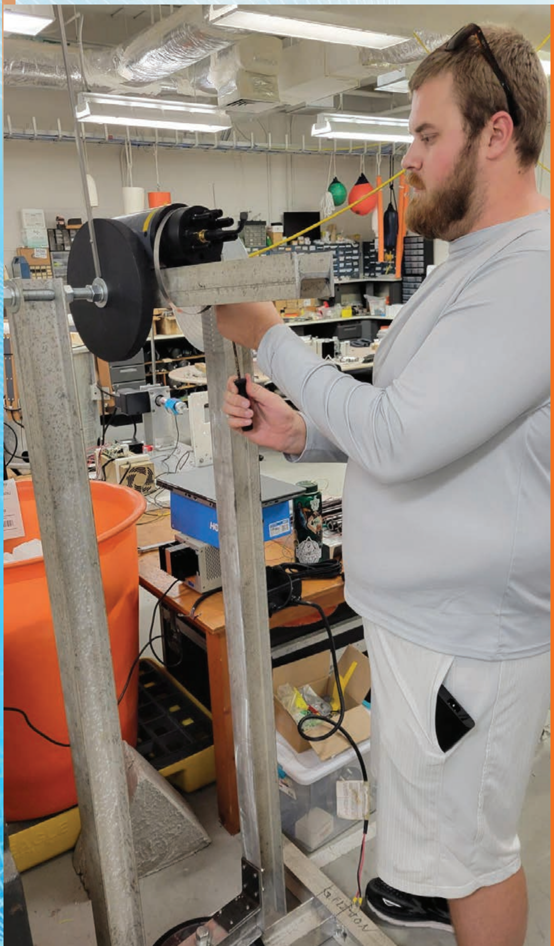
NEEC students getting ready to deploy a Wave Adaptive Modular Vessel (WAM-V) for experimentation.

NSWC Panama City

An Integrated Sensor System for Concurrent Measurement of Electric and Magnetic Fields in the Water Column

Professor:
Manhar Dhanak
Pierre-Phillipe Beaujean

Students:
- **Undergraduate:** 2
- **Master's:** 1



FAU NEEC student is testing an attitude sensing system that he has developed accommodation on the tow fish-based sensor package being developed.

Florida Atlantic University

FAU is developing a compact integrated system of enhanced sensors for concurrently measuring the electric and magnetic fields in the water column or along the seabed from an autonomous underwater vehicle (AUV) with accurate geolocation. A sensor package accommodated in a tow fish for towing from an AUV is being developed. Towing the sensor package isolates the measurement system from the AUV motor and electronics. Previously, we demonstrated that high-quality measurements of the electromagnetic field can be made using a streamlined tow fish towed from an AUV. The integrated sensor system being developed includes (a) a sensitive total field magnetometer; (b) a custom low-noise tri-axial E-field sensor developed at FAU; (c) a depth sensor; and (d) an onboard data acquisition and processing system. Accurate geolocation of the measurement system will be provided through use of an ultra-short baseline (USBL) acoustic positioning system mounted on the AUV. USBL acoustic positioning would provide the range and bearing of the package with respect to a reference point whose GPS location would be communicated to the package via an acoustic modem. The depth of the package would be obtained from the onboard pressure sensor. The information from the USBL, the modem, and the depth sensor would be combined to provide instantaneous geolocation of the package. The focus is on enabling high-quality measurement of baseline electromagnetic fields and those emitted by anomalous sources in the field. The project is in the area of AUV sensor development and supports the Navy's interest in advanced sea platform performance, and advanced sea platform and autonomy science and technologies.

FAU NEEC student is developing a test rig for testing a vehicle attitude sensor package he has developed.

NSWC Panama City

Geomagnetic and Bathymetry Based Navigation System for an AUV

Professor:
Manhar Dhanak
Edgar An
Pierre-Phillipe Beaujean

Students:
- Master's: 2

Florida Atlantic University

In Global Positioning System (GPS)-denied areas, autonomous underwater vehicle (AUV) navigation would typically be based on an onboard inertial navigation system (INS) and a Doppler velocity log (DVL), possibly aided by acoustic positioning from external acoustic transponders. In the absence of acoustic transponders, the vehicle uses INS to dead reckon its path. Navigation inaccuracies in predicted paths arise through environmental disturbances, including currents. If available, acoustic transponders enable the AUV to determine its position relative to a surface ship or buoys and thereby enable positional corrections. However, there are limitations with acoustic positioning in that the range of the transponders is limited and, in the absence of GPS, the surface ship would have to be stationary. An alternative approach is geophysical navigation, involving utilization of environmental features for localization, using sonar, stereo cameras, or magnetic field maps. Here, we propose development of algorithms and implementation on a REMUS AUV of a technique involving use of INS and a DVL with positional correction based on geomagnetic and bathymetric information. The method is based on geomagnetic navigation of certain aquatic animals and utilizes available a priori reference maps of geomagnetic and bathymetric fields. Algorithms, involving a Kalman filter, will be developed that primarily use INS plus a DVL to navigate to a destination, make required corrections to the path through measurement of the local bathymetry and magnetic anomalies using onboard sensors, and match them with available onboard maps of the bathymetry and geomagnetic field. Simulations are being performed using a modeled system to evaluate the performance of the navigation method, both in the absence and in the presence of currents. The developed system will then be implemented on an available REMUS AUV and navigational experiments will be carried out to determine the performance of the vehicle's navigation in the field.

FAU NEEC student checking the alignment of a sensor package on a REMUS AUV.

FAU NEEC student working on developing an algorithm for bathymetry-based AUV navigation.

NSWC Panama City

Bridging the Gap Between Artificial Intelligence and Expert Interpretation in Naval Environments

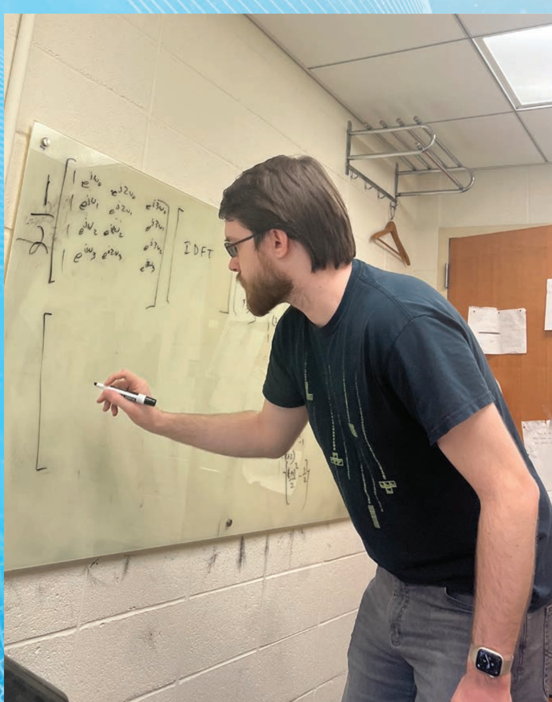
Professor:
Ananya Sen Gupta

Students:
- **Undergraduate:** 4
- **PhD:** 2

University of Iowa

The broad objective of this project is to develop a robust physics-cognizant mathematical framework for sensing the marine environment in battlespace scenarios. We will study and develop interfaces between the feature dictionaries and popular machine learning techniques with the aim of detection, representation, and simulation as well as classification of acoustic signals of naval interest. As appropriate, we will develop supervised and semi-supervised machine learning techniques that allow "opening the black box" for domain interpretation and incorporation of domain constraints (e.g., number of elastic wave orbits in sonar targets, water-sediment interface in buried acoustic sensors). Specifically, this project has two independent thrusts related to naval sensing of the oceanic environment using acoustic signals:
(i) Automatic target detection of small elastic targets using domain-interpretable features: we will develop feature extraction and machine learning algorithms that can autonomously differentiate between different classes of acoustic reflections from small-size underwater sonar targets with complex spectral profiles. We distinguish automatic target recognition in this thrust to be very different in scope and aims than other forms of target recognition, e.g., in detection and classification of target highlights from submarines in anti-submarine warfare. One US graduate student has been recruited to perform and develop this research thrust into a thesis.

(ii) Simulation framework and related signal processing and machine learning techniques for robust acoustic sensor node placement: the simulation setup takes into account local oceanic conditions and current channel state as well as physical constraints such as non-R2 propagation loss along multipath arrivals between nodes, effect of water-sediment interface in acoustic wave propagation, etc. The node placement and analysis techniques leverage the PI's recent and continuing work in physical layer acoustic communications and also explores several new directions such as the cross-layer interface between the physical and network layer, opportunistic signaling as well as local dynamic node placement to optimize communication between neighboring nodes in an underwater sensor network. One US graduate student has been recruited to perform and develop this research thrust into a thesis.



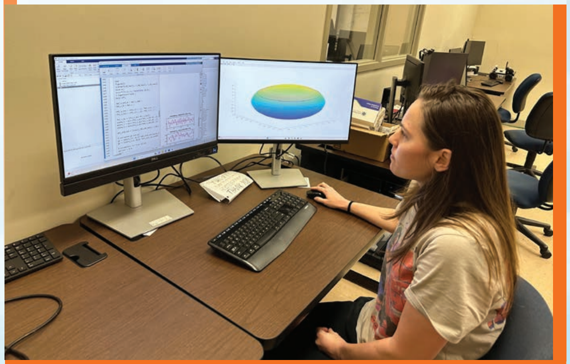
U Iowa – Equations: NEEC student formulating equations for autoencoders used in robust physics-cognizant mathematical framework for sensing the marine environment.

U Iowa – NEEC student meeting on Zoom with Prof. Sen Gupta to discuss the project.

Collaborative Autonomy in Uncertain Environments: Exploring Vistas Beyond Consensus

Professor:
Avimanyu Sahoo
Vignesh Narayan

Students:
- **Undergraduate:** 1
- **Master's:** 1
- **PhD:** 2


NEEC student working on learning models.

University of Alabama in Huntsville and University of South Carolina

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

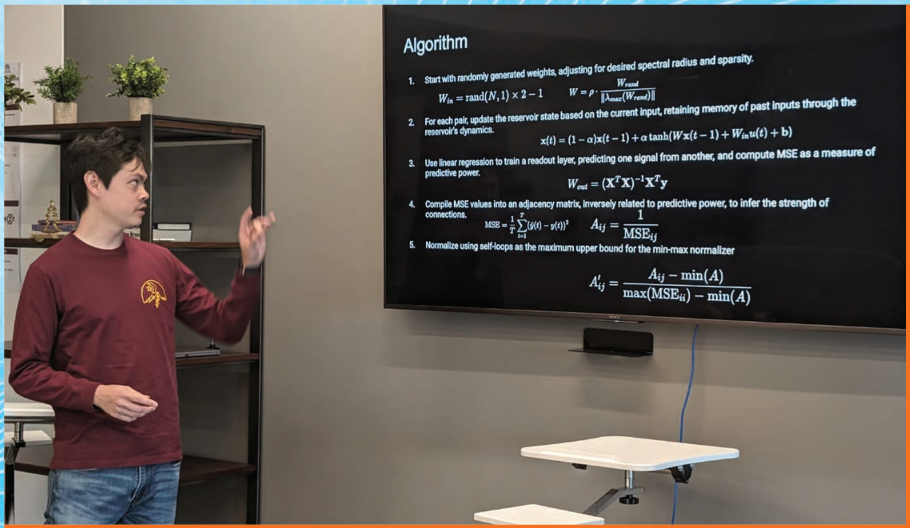
UNIVERSITY OF South Carolina

Networked autonomous, heterogeneous agents (NAHAs) performing collaborative tasks are ubiquitous in diverse applications, e.g., marine exploration and disaster management. To complete these tasks in an uncertain environment, NAHAs require significant wire communication among the agents and computing resources for learning and coordinated control. However, higher communication (data-sharing), e.g., in reconnaissance operations, threatens privacy and risks the security of NAHAs performing coordinated tasks. Moreover, once a cyber-attack or fault is detected, the massive scale and heterogeneity of NAHAs make it challenging to isolate the faulty or attacked agent to restore (even degraded) operation before it cascades to the others.

The overall objective of this project is to design efficient aperiodic communication protocols and, privacy-preserving and scalable learning algorithms for resource-conscious control strategies for NAHAs.. We aim to exploit the structural and dynamic properties of the autonomous agents and establish fundamental theories to identify system dynamics form data, estimate system states, and develop control schemes that are robust to loss of or limited communication, preserve privacy, and facilitate the isolation of compromised agents. The project has three tasks: 1) learning the system model using limited and optimal data from all agents in a distributed fashion, 2) developing resource efficient state estimation and control for the multi-agent systems by learning the uncertain environments, and 3) experimentally validate the results using a networked multi-agent system consisting of ground robots and aerial vehicles.

The success of this research will lead to transformative solutions by instituting a holistic framework for communication, control, data privacy, and security for multi-agent collaborative control, which is significantly important for the Navy. The research results have potential naval applications in the areas of 1) unmanned systems with robust autonomy, precision navigation, and reliable decision-making and 2) command, control, and communication to safely and reliably launch and recover unmanned underwater and surface vessels.


NEEC student presenting a learning and cooperative control algorithm for a NAHA system.



NEEC student adjusting a mobile robot in preparation for an experiment.

NSWC Panama City

Robust and Reversible Deep Networks

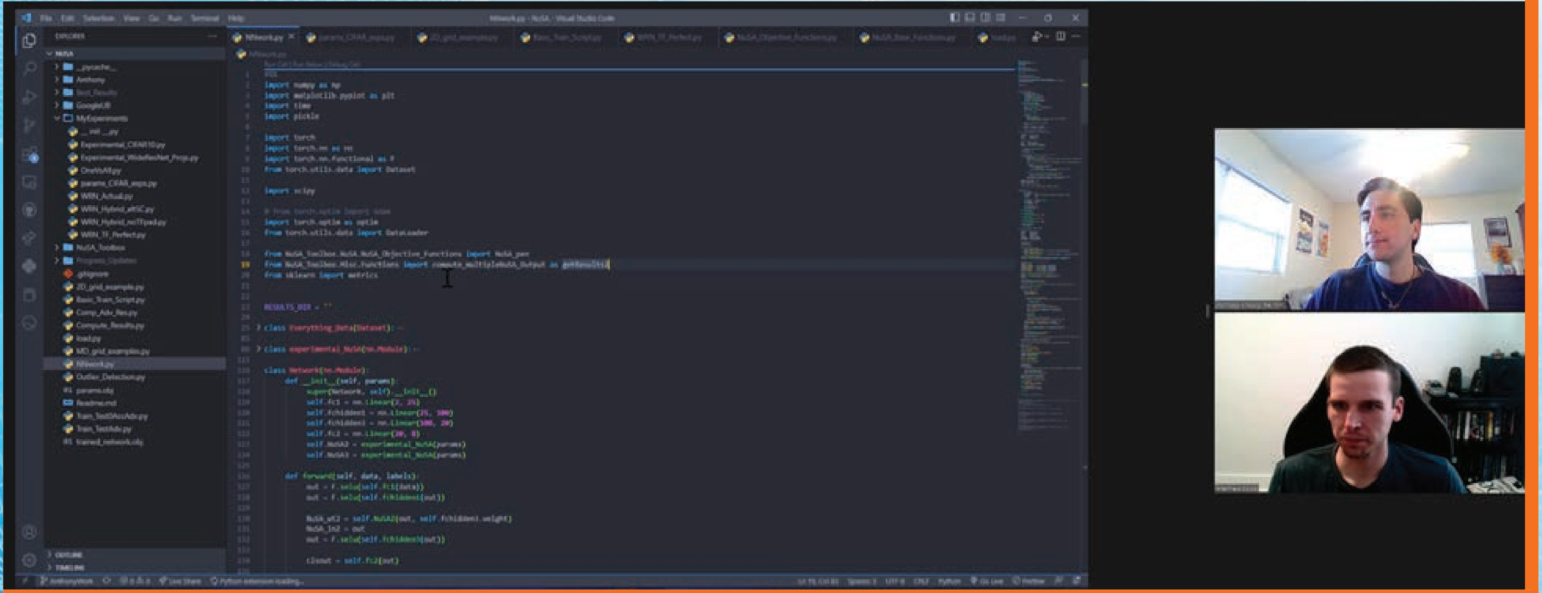
Professor:
Alina Zare

Students:
- **Undergraduate:** 1
- **PhD:** 2

University of Florida

UNIVERSITY of FLORIDA

Neural networks (NN) have become more ubiquitous and have achieved state-of-the-art results in many areas but suffer from a lack of robustness. We are improving NN robustness in terms of handling large changes in inputs that produce a small change in the output. We leverage the NN's null space information at each layer to directly integrate an outlier detection method into an NN used for classification. Additionally, we are looking at mechanisms to specify NN experiments and architectures and to enhance robustness during development and implementation of NNs. The mechanisms we have been focusing on leverage category theory to diagrammatically outline NN experimental scenarios that can be translated into an implementation in an automated way.



NEEC students meeting with Prof. Zare to discuss the project.

Sea Floor Characterization from Free Fall Penetrometer Using Machine Learning

Professor:
Nina Stark,
Alba Yerro,
Anuj Karpatne,
Adrian Rodriguez-Marek

Students:
- **Undergraduate:** 2
- **Master's:** 5

Virginia Polytechnic Institute and State University

Seabed properties and conditions can vary significantly on different spatiotemporal scales. The composition of seabed sediments as well as geomechanical properties is important for a number of physical processes related to sediment transport, geomorphology, and seabed-object interaction, among others. Those processes impact many naval applications, including acoustic surveying, mine burial, and navigation. In-situ seabed testing using penetrometers can provide crucial seabed information to reduce uncertainty for many of these applications. Free fall penetrometers (FFP), specifically, offer a pathway to rapid seabed characterization without the need for larger support infrastructure; thus, FFPs are a convenient tool for geotechnical seabed characterization for naval applications.

Portable FFPs typically measure acceleration and pore pressure to assess the geotechnical properties of the seabed. FFP data collection is reliable, reproducible, and sensitive to small variations in seabed conditions. However, interpretation of the data for geotechnical seabed parameters depends on an expert data analyst to process the raw data into an informative and broadly accessible product. This research project focuses on exploring machine learning for FFP-based seabed characterization. Thus, the goals of the proposed study are to: (a) prepare an FFP database for training and validation of numerical model and machine learning algorithms; (b) develop an initial machine learning algorithm for seabed classification from FFP accelerometer recordings and pore pressure readings; (c) expand an existing numerical model to investigate the physical processes governing the seabed classification; and (d) investigate the uncertainty of seabed classification from FFP data by using machine learning and comparing it to in-situ seabed classification from core sampling.

A large FFP database is being considered in this study; it contains data from different locations in the US and worldwide collected by Dr. Stark and her team and also includes publicly available data collected by other researchers. The database was assembled and formatted by students under the guidance of Dr. Rodriguez-Marek. In another effort, a numerical model initially proposed by Dr. Yerro and her team for a portable FFP using the material point method is being expanded to account for different hydraulic conditions and sediments. Finally, a machine-learning algorithm is currently being developed under the guidance of Dr. Karpatne to be trained with the field database complemented by synthetic numerical data.

VT students learning about and testing a side scan sonar in river near Blacksburg, VA.

VT student dropping the PFFP BlueDrop on a windy day in Duck, NC.

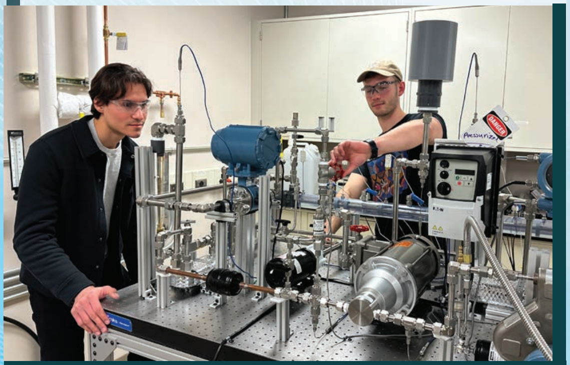
VT students learning how to deploy equipment of a LARC from personnel at the Army Corps Field Research Facility.

NSWC Philadelphia

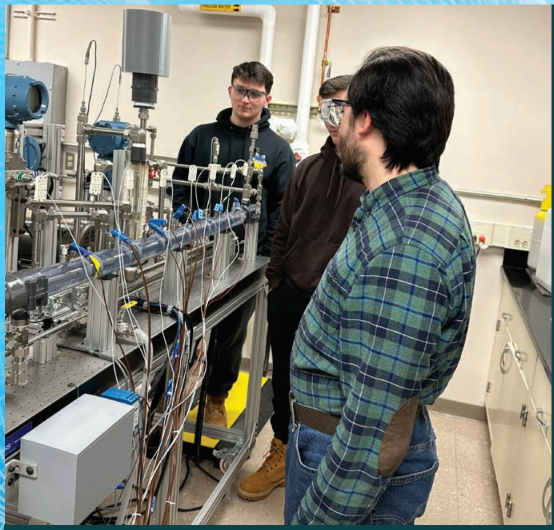
Investigation of Low Global Warming Potential Refrigerant Alternatives for Naval Chillers

Professor:
Brian Fronk

Students:
- Undergraduate: 6
- PhD: 1



NEEC students



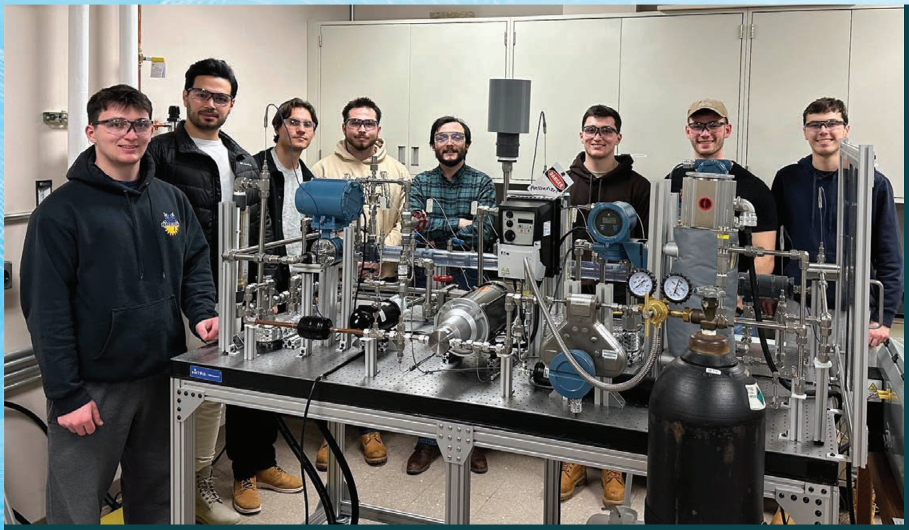
NEEC students

Pennsylvania State University

Navy shipboard chillers, modular refrigeration units, and other vapor compression systems rely on hydrofluorocarbons (HFCs) as working fluid. National and international legislation is driving a reduction in HFCs to mitigate concerns over the high global warming impact from fugitive refrigerant emissions. Because of the impending phase-out of HFCs, the pressing challenge of identifying alternative refrigerants for naval applications will require a workforce of engineers with expertise on refrigerants and chiller systems. As mechanical engineering curricula have broadened, the typical bachelor's level mechanical engineering student course of study now receives limited training on air conditioning and refrigeration systems, often only in one or two lectures as part of an introductory thermodynamic course.

Thus, this project aims to provide students with a combination of fundamental and applied domain knowledge to support the naval research and operational enterprise. The program combines hands-on experiments with refrigerants, computational modeling of Navy chiller systems, and asynchronous, online modules on specialty refrigeration topics. The first cohort of undergraduate and graduate students has built and commissioned a test facility designed to evaluate phase change heat transfer and pressure drop characteristics of candidate replacement refrigerants during condensation and evaporation. The system can operate at pressures up to 300 psia with condensation and evaporation heat duties up to 10 kW using HFC and hydrofluoroolefins (HFO) A1 and A2L refrigerants. The facility will be used to support the training of annual undergraduate student cohorts consisting of 5 to 7 students.

Complementing the experimental campaign is the development of a thermodynamic model of a representative 500 refrigerant ton centrifugal chiller. A conceptual centrifugal compressor design was developed based on the baseline of R-134a. Performance curves were then generated for different candidate A1 refrigerant replacement and used to assess degradation in chiller performance for representative naval operating conditions, assuming the shipboard components are unchanged. Initial research results highlight the performance challenges of "drop-in" replacement of refrigerants in centrifugal plants. The developed educational modules can be packaged and offered to other entities to pilot similar training programs.



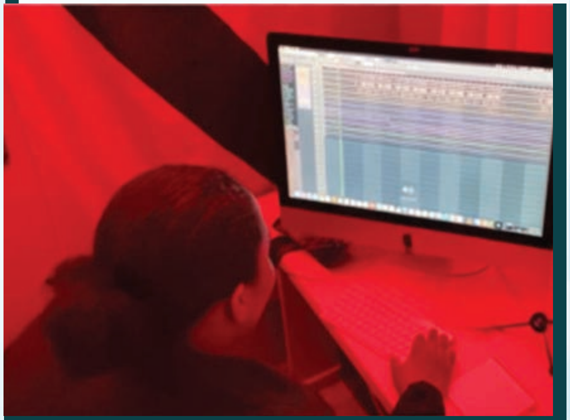
NEEC students

NSWC Philadelphia

Unifying and Securing Naval SCADA Networks Through Scalable SDN

Professor:
Liang Du (Temple)
Yan Li (Penn State)

Students:
- **Undergraduate:** 6
- **PhD:** 1



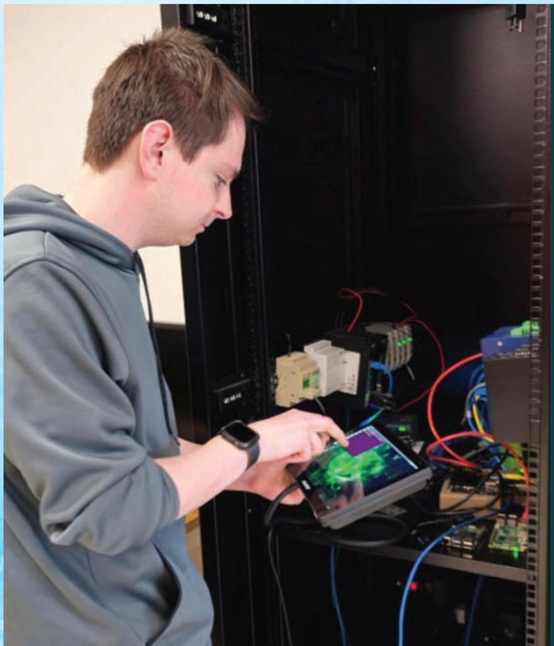
MS student in Cyber Defense and Information Assurance at Temple is programming SDN flow.

Temple University and The Pennsylvania State University

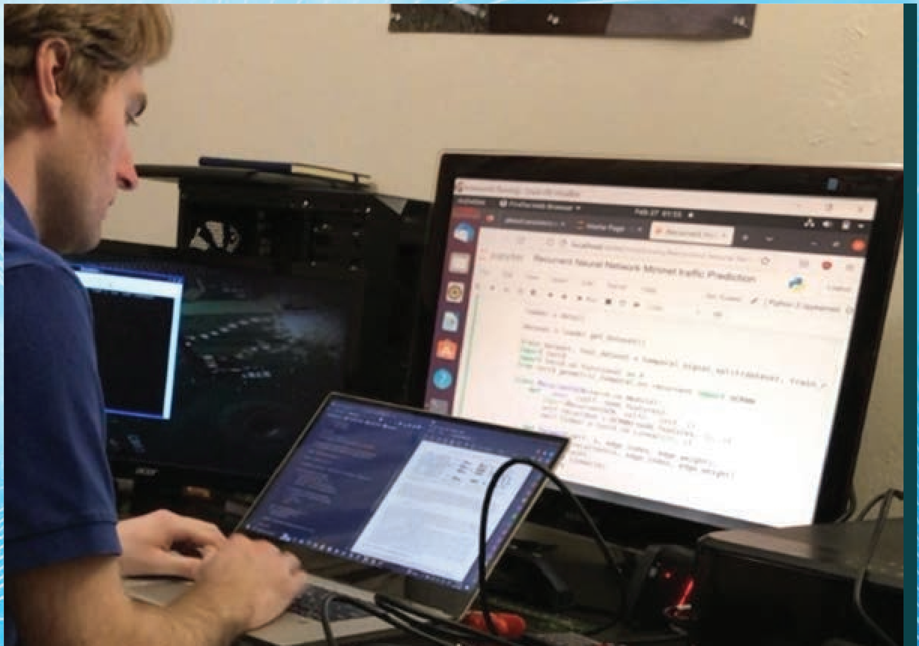
This project aims at designing and utilizing novel, open, and scalable software-defined networking (SDN) techniques to enhance the resiliency/survivability, scalability/compatibility, and security of naval Supervisory Control and Data Acquisition (SCADA) networks. The proposed SDN architecture for naval SCADA networks consists of three parallel planes: data, control, and application, which are designed separately but collectively work together. SDN controllers communicate with the application plane through northbound Application Programming Interfaces (APIs), receive instructions from the application plane, and relay them to corresponding network components. Open-source protocols (e.g., OpenFlow), network emulators (e.g., MiniNet and MaxiNet), SDN frameworks (e.g., Ryu), and packet analyzers (e.g., Wireshark) will be utilized by mentored students to implement flexible simulation environments and carry out quantitative performance analysis.

On the education side, the project aims at engaging, mentoring, and training eligible domestic students from diverse backgrounds at both Temple and Penn State. They will be prepared with hands-on knowledge and programming skills to implement and demonstrate the proposed SDN architecture on simulated shipboard SCADA networks. Trained students will be equipped with sufficient background and experience to pursue careers in naval engineering as potential Navy workforce personnel in the future.

The direct impact of this project will be the development of novel, open, and flexible SDN architectures for naval SCADA networks to enhance network performance and control systems on naval vessels. This project also aligns with DoD's Navy Civilian Workforce Framework by strong student participation.



BSEE Senior at Temple is working on the network setup in Temple lab.



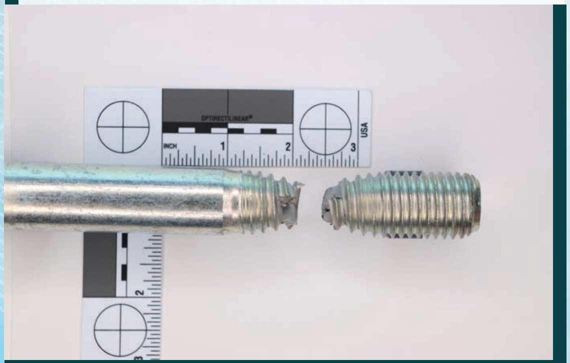
Penn State MSEE student is working on his programs. This student will join NSWC in summer 2024 after completing his MSEE.

NSWC Philadelphia

Validating and Advancing Fastener Design for Tensile Loads

Professor:
Mark Denavit

Students:
- **Undergraduate:** 3
- **Master's:** 2



Tensile failure of a 1 in. diameter bolt.

University of Tennessee, Knoxville

The Navy uses a federal standard to design threaded connections. The provisions of this standard were developed long ago and the original research from which the provisions were developed is no longer available for review, leading to uncertainty in design. Furthermore, applications of threaded connections have expanded beyond the original scope of the standard, raising questions on the applicability of the provisions to other cases. Given the need for efficient connections that achieve the high performance and service life demands of the marine environment, a reevaluation of the fundamental behavior of fasteners is warranted.

The overall objective of this project is to experimentally validate the accuracy of existing design equations and create formative experiences for students that encourage them to pursue a career in naval engineering. The technical approach to achieve this objective includes the following: 1) developing and validating an experimental system and procedures for the precise evaluation of the tensile strength of fasteners; 2) performing experimental testing on a comprehensive suite of parameters for Grade 5 fasteners in the first year and fasteners of other materials in subsequent years; 3) evaluating existing design equations and developing modifications as appropriate; and 4) curating and archiving experimental data to ensure long-term availability. Throughout the project, engaging hands-on experiences for students will be created with the goal of increasing awareness and driving interest in careers in naval engineering.

The following outcomes of this work are anticipated: 1) a wealth of data on the tensile strength of threaded fasteners will be generated; 2) equations for design will be either validated or improved, enabling better fastener designs; and 3) students not otherwise exposed to the field of naval engineering will be provided with experiences that develop knowledge, skill, and interest in fastener design for naval systems.

Undergraduate student performing harness testing on bolt sample.

Master's student preparing a bolt tension test.

NSWC Port Hueneme

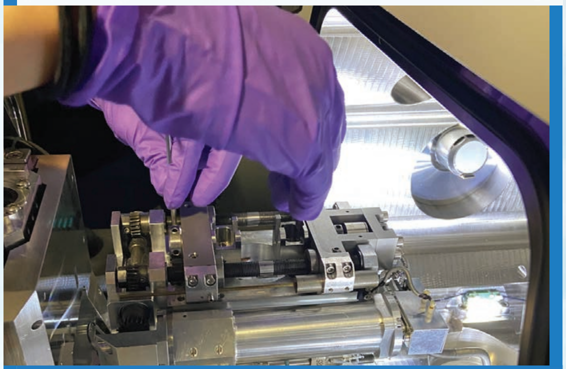
Understanding Processing-Structure-Property Interactions in Additively Manufactured Ferrous Alloys

Professor:
Samantha Daly

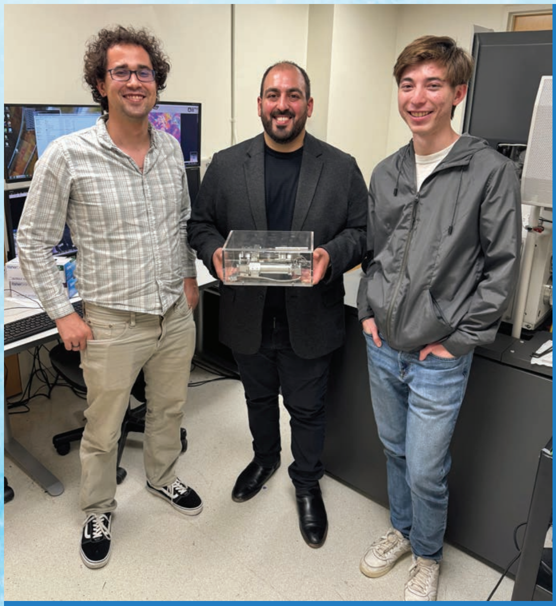
Students:
- **Undergraduate:** 3
- **PhD:** 1

University of California, Santa Barbara

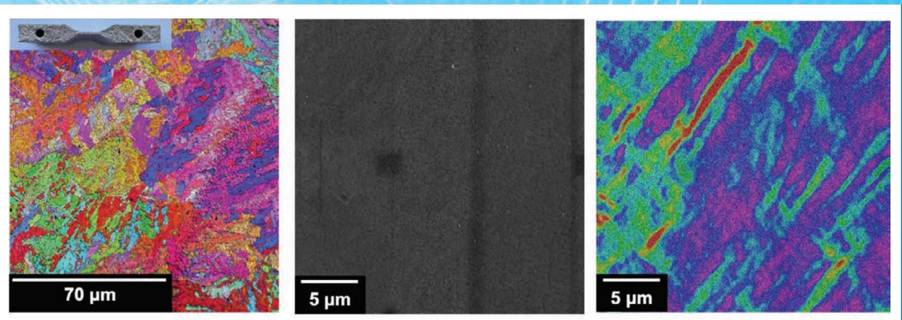
As part of the Navy's efforts to advance fleet readiness through sustainable and scalable additive manufacturing (AM), we are investigating how material processing affects mechanical response in AM ferrous alloys, with a focus on as-printed strength and part lifetimes. Ferrous alloys are essential components of on-ship infrastructure and materiel, but they require regular replacement and maintenance, which is logistically costly. For the Navy, AM serves as a logistical accelerator, enabling the on-ship printing of serviceable parts based on operating need. However, to effectively utilize the on-ship and flexible design capabilities of AM, it is critical to understand how the strength and lifetimes of AM parts will depend on the print parameters that are input into the AM process, and how the resulting mechanical properties of the manufactured parts will differ from existing technically certified systems. To explore the strength of ferrous AM components, localized damage nucleation and progression in AM printed specimens are measured at the microscale in real time under load, using an approach known as Scanning Electron Microscope Digital Image Correlation (SEM DIC), which is coupled with high-resolution electron backscatter diffraction (EBSD). With SEM DIC, specimen failure can be correlated directly to specific microscale structures of the printed parts resulting from AM processing choices, which can be used as a basis of comparison to current technically certified forged and machined parts. Initial studies performed on additively manufactured M2 maraging tool steel showed plastic deformation with reduced elongation and dramatically reduced corrosion resistance, prompting a design change to AM 316 stainless steel. From a characterization perspective, the nanoscale structure of these AM parts presents opportunities to resolve deformation behavior with SEM DIC on smaller scales than previously realized, with pixel resolutions at less than 10 nanometers in length. Additionally, the combination of SEM DIC and EBSD allows for multiscale comparison across several orders of magnitude in sample scale, allowing for detailed comparisons with existing technical certifications. Overall, this project will provide high-resolution information on AM part mechanical capabilities that will strengthen and expand the Navy's industrial base to better achieve strategic defense objectives.



The micro-load frame which is less than 12 in long, gets loaded into the microscope chamber by NEEC students so that samples can be tested under vacuum while being imaged by the electron beam.



NSWC PHD NEEC Director Armen Kvryan, PhD (middle) shown with project members, alongside SEM DIC microscope and equipment.



M3 maraging tool steel print blends are imaged using EBSD to map grain structure (left), before being coated in silver to create an ultrafine speckle pattern of size ~10 nm (middle), which is then tracked during sample loading to map strain and local material deformation (right).

NEEC

Naval Engineering Education Consortium

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NC State University
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Michigan Technological University
Penn State
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