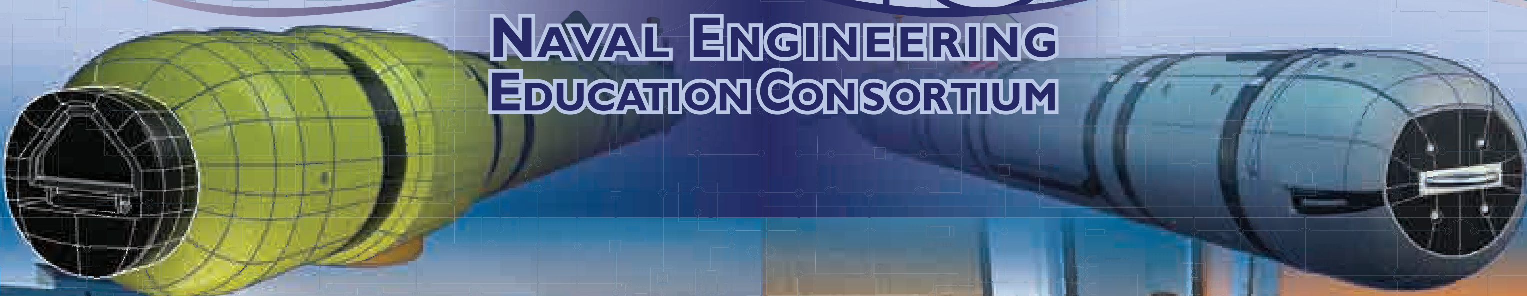
NAVAL ENGINEERING EDUCATION CONSORTIUM PROCEEDINGS

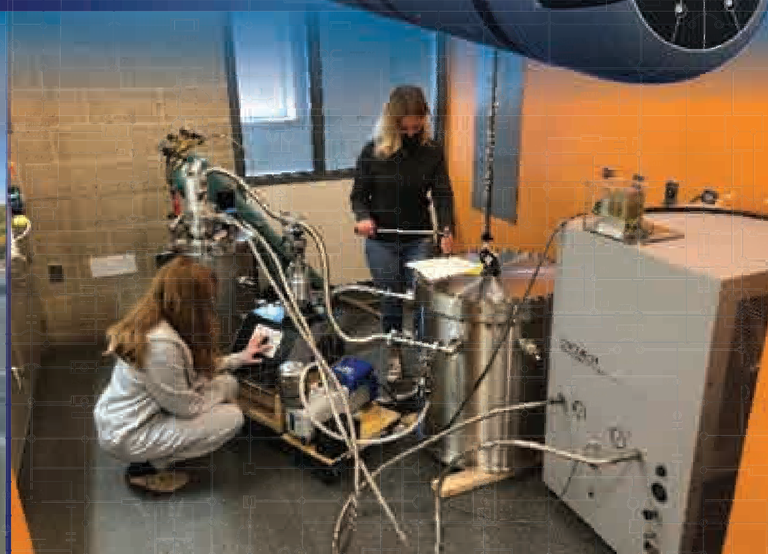
AMERICA'S NAVY

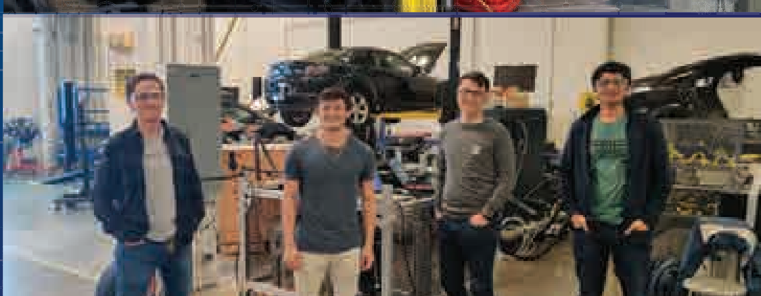
NAVSEA WARFARE CENTERS

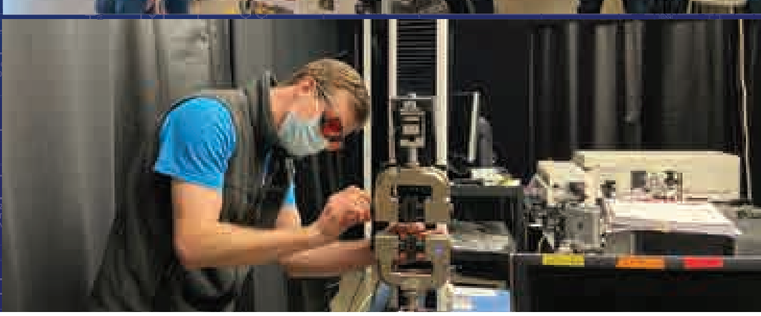
2022 NEEC

Naval Engineering Education Consortium









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Message from the Executive Director

It is my great pleasure to present the fifth annual Proceedings of the Naval Engineering Education Consortium (NEEC), which describes the NEEC research projects carried out in 2021 and highlights ongoing and future projects. The activities in this year's NEEC Proceedings reflect the energy and commitment of a group of dedicated people across the country who have accomplished a great deal under challenging conditions. I would like to thank the students and the professors, the scientists and engineers, the mentors, government grants officers, and the NEEC Directors for their efforts on behalf of the NAVSEA Warfare Centers, the Navy, and the nation.

Navigating our way through the uncharted waters posed by the COVID-19 pandemic continued to be a defining feature of 2021 for the NAVSEA Warfare Centers and the NEEC. We've responded by seeking to strike a balance between persistence and flexibility. To remain agile as we work to Expand the Advantage, we updated our Strategic Plan in April 2021, and identified the pathways to success via our mission priorities, strategic goals, and foundational values.

Our five modified strategic goals are:

1. Workforce and Leadership Development
2. Mission-Aligned Strategies at the Division Level
3. Technical Innovation and Excellence
4. Business Excellence and Improvement
5. Right Culture/Values

The NEEC program plays a critical role in advancing a number of these goals. Funding academic research and attracting students to Navy-related engineering programs at the Warfare Centers helps to both widen and deepen the pool of qualified scientists and engineers. The students we inspire today to pursue engineering may well become members of our workforce of tomorrow, or participants in the many academic and industrial partnerships that apply their creativity to solve naval challenges for the Navy of the future. At the same time, the NEEC Program builds bridges to academia and industry, and by working in partnership with the best and brightest minds in industry and academia we can continue to provide technical leadership for the Navy of today, while also supporting preparedness for the Navy of tomorrow. The Navy's technological superiority is not something that was gained instantaneously, so sustaining it will take a steady and concerted effort and we are committed to the NEEC program as a way to generate and sustain the "technology knowledge base" needed.

Sincerely,
Brett Seidle, PhD
Executive Director
Naval Surface & Undersea Warfare Centers

About NEEC

The Naval Engineering Education Consortium was established by the Naval Sea Systems Command (NAVSEA) to develop and attract new professionals into the broad technical fields associated with current and future U.S. Navy ships and submarines. The purpose of NEEC is to increase and maintain a knowledge base for the increasingly sophisticated technologies critical to the design and operation of the complex interrelated systems for the naval and defense acquisition communities.

Directed by NAVSEA Warfare Center headquarters and implemented at ten Divisions across the country, NEEC projects target the Navy's relevant technology needs, with three primary objectives:

- Acquire academic research results to resolve naval technology challenges
- Hire talented college graduates with relevant naval engineering research and development (R&D) experience
- Develop and continue exceptional working relationships with naval engineering colleges, universities, and professors.

Our NEEC participants remained committed in pursuit of important Navy projects ranging from high power laser studies, predictive maintenance of Naval equipment, harnessing quantum controlled algorithms, durability of additive manufactured polymers in marine environments and fouling-resistance elastomeric coatings - to name just a few! Over 440 science and engineering students from over 50 universities participated in the program, and demonstrated remarkable flexibility and inventiveness to succeed despite limitations still imposed by the pandemic.

NEEC engages in project-based research within academia that targets the Navy's technology needs, acquired or developed in-house, and cultivates a future science and engineering workforce. Through NEEC, the Navy funds research and development projects at academic institutions to engage professors and their students to work alongside knowledgeable personnel familiar with the Navy's technology challenges. Formal partnerships are established via a grant award that defines naval-related projects with student participation. Grants awarded provide a way for the Warfare Centers technical workforce to connect with academic expertise and students at the university.

We are confident that our path ahead will be even more successful as we build on a foundation of teamwork, powered by the energy of scientific curiosity. We look forward to what that future brings, and to sharing it with our academic partners, students, and graduates who join the NAVSEA workforce to enable maritime superiority today and into the future.

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

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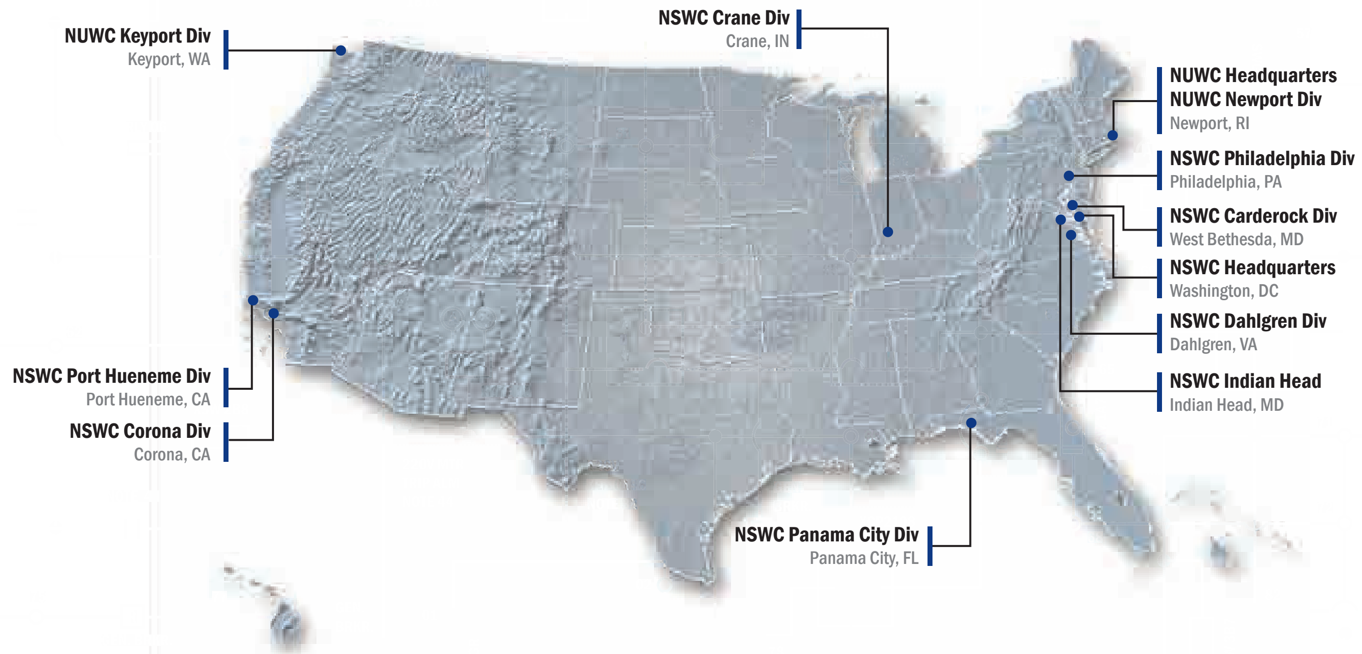
About the Warfare Centers at the Naval Sea Systems Command (NAVSEA)

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, Corona:
Karon A. Myles

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

Naval Surface Warfare Center Division, Port Hueneme:
Alan W. Jaeger
and Ramon Flores

NSWC Carderock

Robust Multi-Domain Situational Awareness through Sensor Fusion

Professor:
Eric J. Coyle

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

Embry-Riddle University

EMBRY-RIDDLE
Aeronautical University
DAYTONA BEACH, FLORIDA

One of the key challenges to widespread integration of unmanned assets in Navy missions is the inability of the systems to coordinate efforts as effectively as manned systems. As such, there are a variety of Navy missions that could benefit from the coordinated efforts of aerial, surface and underwater unmanned systems to perceive the environment, which leads to improved situational awareness. This research investigates standardized methods of representing, fusing, and processing perception data collected from multi-domain unmanned assets.

The research conducted under this project has collected UAS Lidar, UUV forward-scan Sonar, and USV Lidar and Radar measurements of the maritime environment. The team used spatial transforms and false positive rejection techniques on each sensing modality to yield a point cloud in the global reference frame. It was then shown that the same processing technique can be effectively applied to each of these point clouds. The chosen processing technique is a custom designed algorithm that leverages machine learning and computational geometry to cluster, classify, and extract concave hull bounds of each object in the global frame. Finally, a mapping tool was developed that fuses the objects collected over time and across sensing modalities into a single 2D map of marine objects. The team has also collected maritime imagery across the aerial, surface, and underwater domains for the purpose of investigating the effectiveness of deep learning detection networks through transfer learning. Initial results have shown these techniques to be effective on surface and aerial imagery, with underwater imagery yet to be labeled and tested. An additional focus of this research is to enable these techniques to run on the unmanned systems in real time rather than offline in post-processing.

NEEC students testing at DeLeon Springs State Park. The algorithms developed in this research have the potential to significantly impact both conservation efforts and unmanned system situational awareness.

NEEC Students preparing to flight test the fully instrumented Tarot X6 UAV.

NSWC Carderock

Senior Design Project in Support of Naval Applications

Professor:
Pierre-Philippe Beaujean

Students:
- Undergraduate: 24

Florida Atlantic University

Senior students in the Florida Atlantic University (FAU) Ocean Engineering (OE) program have developed (semi-) autonomous systems of Naval relevance in the course of a two-semester capstone senior design project that involves designing, building, testing and demonstrating complete systems. In addition to the development of the prototype, students must provide design presentations to colleagues and stakeholders addressing requirement development, trade studies, mechanical design and analysis, software design and analysis, construction planning, test planning, risk mitigation planning, budget and schedule.

The students choose their projects from a collection of topics focused on marine robotics and energy, and work in teams of 6 undergraduate students that are supported by faculty and technical staff. Projects sponsored by the NEEC program include:

- A desalinator powered by the water current driven by tides, that autonomously extract fresh water from saltwater using an ultrasonic apparatus.
- A self-propelled, remotely operated concrete mattress deployment vehicle for use in shallow water.
- A bio-inspired autonomous underwater vehicle propelled by squid-like pulse jet propulsion, capable of sitting on the seafloor, detect a surface moving object based on optical signature, measure its wake and follow this object.
- A bio-inspired autonomous underwater vehicle with self-burying capability, capable of navigating at the water surface to a waypoint, descent on the seafloor, bury itself, return to the surface and to the original mission starting location.

Every project aims to engage students with hands-on experience and promote both student interest and understanding of marine platforms, autonomy science, and naval technology. Every project has been completed and tested, and a Final Design Review took place in April 14, 2022. Figures 1 through 3 show the design, fabrication, testing and team of each prototype.

From left to right: Design, Fabrication, Testing and Team Picture of the Current-Powered Ultrasonic Desalinator.

Design, Fabrication, Testing and Team Picture of the Self-Propelled, Remotely Operated Concrete Mattress Deployment Vehicle.

Design, Fabrication, Testing and Team Picture of the Bio-Inspired Autonomous Underwater with Self-Burying Capability.

NSWC Carderock

Embedded Sensors and Actuators for Structural Health Monitoring using Enhanced Materials in Additive Manufacturing

Professor:
Jose Garcia-Bravo (Lead)
Brittany Newell (co-Lead)
Tyler Tallman (co-Lead)

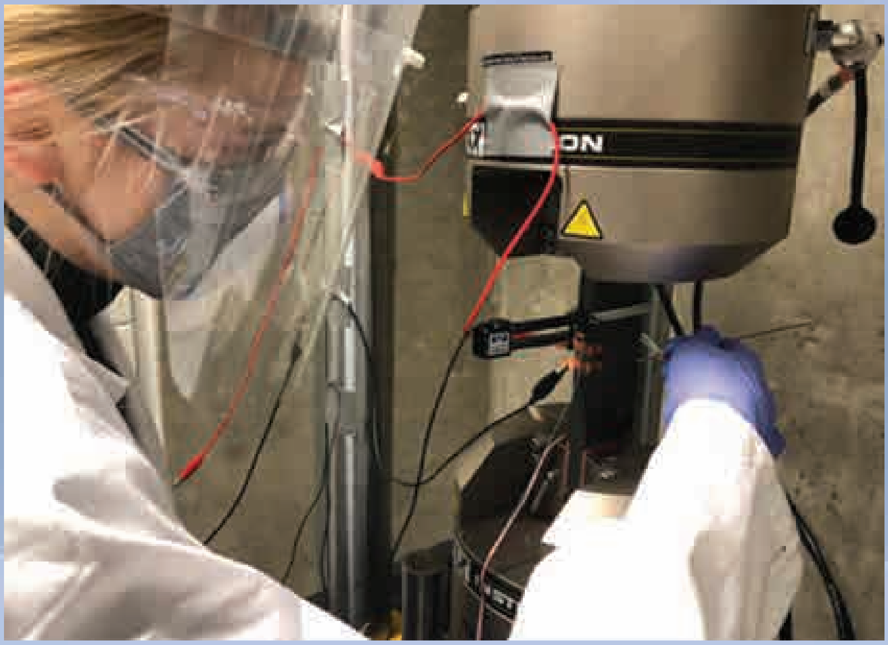
Students:
- **Undergraduate:** 4
- **PhD:** 2

Purdue University

Multifunctional Additive Manufacturing (AM) has immense potential in advancing the field of Structure Health Monitoring (SHM) by allowing for piezoresistive materials to be printed onto or embedded within structures. The focus of this project is the production and characterization of multifunctional FDM materials with commercially available FDM 3-D printers, as well as the creation and evaluation of additively manufactured sensors and actuators. This work allows for the production of cost effective piezoresistive devices which can be tailored in-house to meet the demands of SHM systems.

Currently, this project is developing and characterizing novel SHM-focused sensors manufactured from both rigid and flexible materials via multifunctional AM. The materials and processes established are further evaluated by characterizing the performance of 3D printed components across various loading conditions. The Purdue team has been able to experimentally identify optimal production conditions for the creation of piezoresistive filaments, tuned for the manufacturing of self-sensing SHM components. Building upon these findings, the Purdue team has been able to compile one of the most exhaustive investigations within the field to date, revealing valuable insights into the strain sensing capabilities and the in-house production of both rigid and flexible piezoresistive FDM filaments.

Furthermore, the Purdue team has been able to revolutionize the way in which multifunctional materials can be produced by implementing a novel manufacturing procedure for TPU-based filaments. This manufacturing procedure has enabled the production of tailorable multifunctional filaments which are more electrically consistent than any other flexible filament known on the market today. The processes developed by the Purdue team results in a polymeric filament that is ready to be used in conventional FDM printers to manufacture self-sensing 3D printed components.



Undergraduate student performing mechanical testing to characterize the piezoresistive response of 3D printed components..

NSWC Carderock

Control of Autonomous Underwater Vehicles in Stratified Fluids and Near-Surface Operations

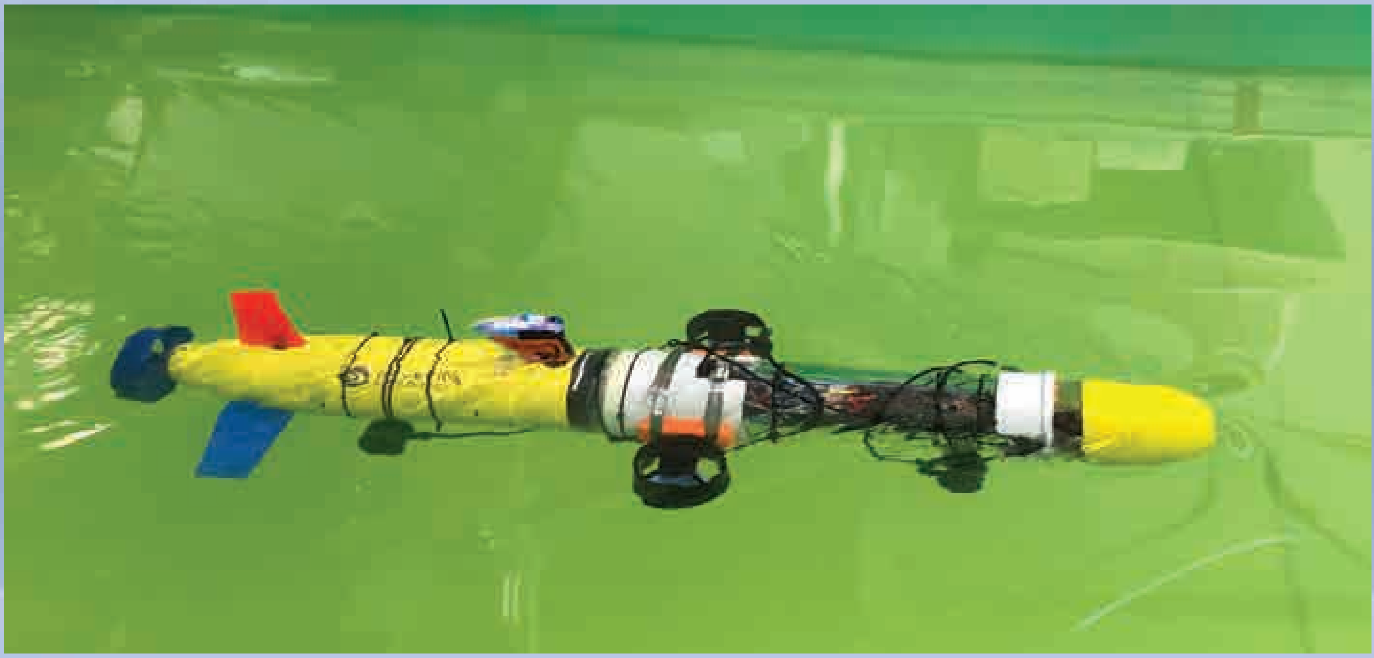
Professor:
Stephen Licht

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

University of Rhode Island

Submarine hull hydrodynamics and propeller performance are generally well-characterized in open water conditions. Techniques for depth, speed, and heading control in open water are thus well understood and straightforward to automate on unmanned platforms. However, when operating near the surface, in the presence of obstacles, or in stratified flows with steep density gradients, there can be significant additional interactions between hull, propulsor, and control surfaces and the surrounding fluid. These poorly modeled interactions can result in undesirable behaviors, including loss of depth control and breaching. Control problems are especially acute when operating at slow speeds, as dive planes and rudders require forward speed in order to maintain control authority.

NSWC Carderock has a long-term responsibility for maintaining subject matter expertise in dynamic modeling and control of underwater vehicles. NSWC Carderock is also charged with advancing the current state of the art in submarine hydrodynamics, control, and autonomy. The proposed effort is designed to address both of these needs. Over the course of this effort, we will introduce students seeking bachelor's, master's, and PhD degrees to fundamental principles of underwater vehicle modeling, simulation, and control through hands-on experimental research, enhanced course offerings, and direct involvement with research efforts performed in collaboration with NSWC Carderock engineers.



Micro-AUV testbed with added cross-body thrusters and buoyancy control engine for in water testing of over-actuated depth control algorithms.

NSWC Carderock

A Multi-Scale, Multi-Physics Solution to Inform Water Bottle Recycling at U.S. Navy Makerspaces

Professor:
Stephanie TerMaath

Students:
- Undergraduate: 16

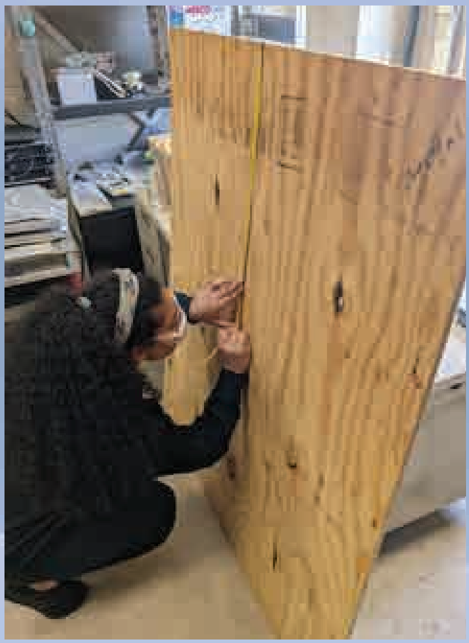
University of Tennessee, Knoxville

To prepare students for Navy-relevant careers, three senior design teams are performing material and structural engineering projects of importance to the U.S. Navy. Efforts provide novel solutions for Navy engineering and operations in additive manufacturing and environmental sustainability, while developing technical skills and hands-on experience throughout the entire research and design process.

Water Bottle Recycling using a 3D Printer.
To recycle PET plastics shipboard and in makerspaces, the goal of this project is to design a modification to household 3D printers that enables the 3D printing of shredded water bottles.

Water Bottle Shredding.
In order to achieve a quality print with recycled plastic, the plastic must first be grinded into uniformly sized pellets. The goal of this project is to build a device to shred water bottles to a specified pellet size.

Standardized Shear Testing of FFF Polymers.
The certification of parts produced using Fused Filament Fabrication (FFF) requires accurate and reliable strength and structural integrity assessment of the parts. In particular, the strength of the many interfaces within FFF material (the bond between deposited layers or beads) must be well characterized. The goal of this project is to investigate the existing ASTM standards for characterizing shear in composites and then design, build, and validate an improved testing apparatus and specimen geometry for shear strength testing of polymer FFF material.



Student designing the water bottle stand.

Student preparing to test a shear specimen.

Students printing water bottle pellets.

NSWC Corona

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:** 1

University of California, Riverside

This project will harness quantum optimal control algorithms that use and enable new machine learning applications for data science and the broader quantum information sciences. In contrast to existing machine-learning algorithms that use/enable classical calculations (i.e., conventional neural networks based on classical computation), this project represents a transformative departure by harnessing quantum computing to increase the capabilities of classical machine learning using quantum states and systems. Predictive quantum control calculations are first utilized to create a quantum training dataset (i.e., magnetic signal strength, pulse shape, and excitation frequency) that enables machine learning algorithms to construct tailored optimal pulse shapes that initialize qubit arrays into desired quantum states.

This initialization process will subsequently enable quantum algorithms that can be used to analyze quantum states instead of classical data. Together, these initiatives support NSWC Corona's program goals to educate and train the next generation of students for advancing Naval mission priorities in quantum information science.

Dr. Wong and students.

Dr. Wong and students.

NSWC Corona

High-Performance Post-Quantum Cryptography

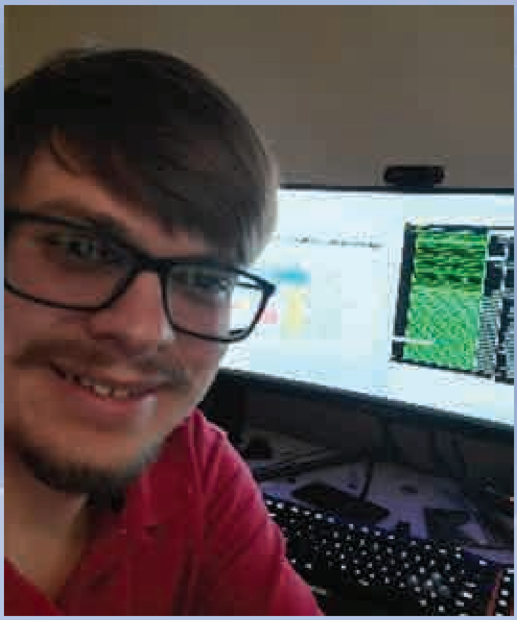
Professor:
Reza Azarderakhsh

Students:
- PhD: 2

Florida Atlantic University

Per the US government's recent act on the modernization of cybersecurity and inclusion of quantum-resistant cryptography, it is of paramount importance to upgrade existing security protocols in use by the Navy to new ones with post-quantum cryptography. At FAU, we are already on top of this and have already developed high performance cryptographic solutions to be employed and deployed with quantum safe key exchange. This will help protect the Navy from cybersecurity threats before quantum computers are fully operational. In our first two years, we have developed capabilities and high-performance solutions useful for secure and quantum-safe security of data in-transit.

The FAU team is very capable and well-trained for this project and is one of the unique universities working on post-quantum cryptography and supporting standardizations which are on-going at NIST now.



FAU student working.

FAU student working.

NSWC Corona

Predictive Maintenance of Naval Equipment using Text Mining

Professor:
David M. Goldberg (PI)
Aaron C. Elkins
Bongsik Shin

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

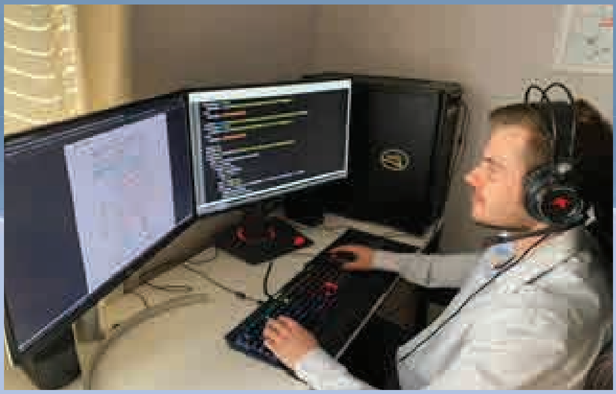
San Diego State University

In support of the Navy's efforts to improve efficiency of maintenance operations, San Diego State University (SDSU) is pioneering research on utilizing naval maintenance logs to predict future maintenance needs. Maintenance concerns represent a substantial portion of the Navy's annual budget, and as equipment has become more technologically complex, these concerns also require an enormous level of manpower. Predicting equipment that may be likely to fail or require servicing in advance would substantially streamline maintenance operations. In addition, ensuring that equipment is serviced efficiently also safeguards naval readiness.

The interdisciplinary SDSU research team is dedicated to tackling this problem by searching for key words and phrases used frequently in maintenance logs before equipment failures. The team has developed algorithms to detect "smoke terms," such as "leak" or "crack," which will allow them to predict maintenance needs in the Navy's ongoing operations. By examining which logs contain many smoke terms, ongoing maintenance can specifically target the most at-risk equipment. The team is currently developing visual dashboards to allow naval personnel to analyze maintenance logs and determine the most pressing issues.

This NEEC-supported research project enables unique learning experiences for both undergraduate and graduate students at SDSU, and the research findings will have a long-term impact on predictive maintenance efforts.

Graduate and undergraduate students



Graduate student working.

Graduate student working.

Advanced Data Visualizations for Robust Machine Learning

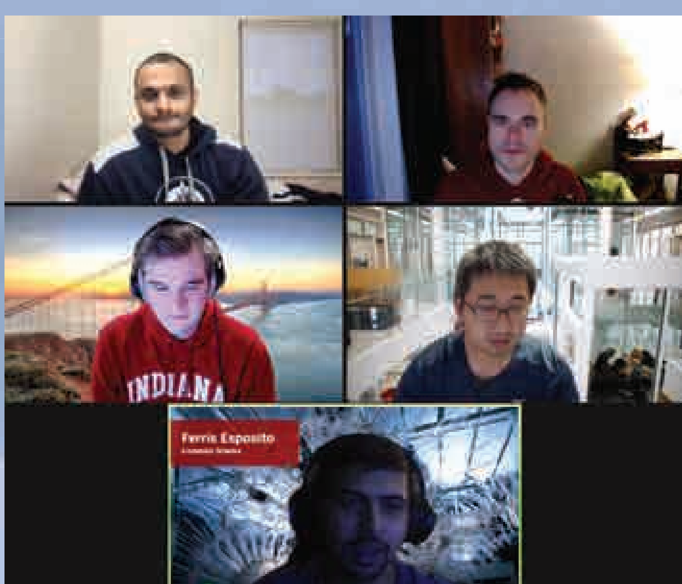
Professor:
David Crandall
Katy Borner

Students:
- **Undergraduate:** 11
- **Master's:** 5
- **PhD:** 4

Indiana University

Recent progress in machine learning has led to impressive advances in Artificial Intelligence in the last few years. Computers now outperform humans on a surprising variety of tasks, from games (e.g., Chess, Go, and trivia), to language problems (e.g., speech recognition and translation), to computer vision tasks (e.g., identifying animal species, recognizing faces, reading lips). However, machine learning failures can occur because machine learning algorithms rely on fitting complex mathematical models to training data. When very large, high-quality training sets are available, deep networks can readily learn a model for nearly any dataset. However, when training sets are small or biased, as often happens in practice, the networks "overfit" the training data while performing unexpectedly, erroneously, and even nonsensically on new examples. Moreover, given the complexity and black box nature of these models, it is usually difficult to debug or fix a failure.

Although much work is done trying to build better algorithms, fixing them will be a long-term effort. We propose a fundamentally different approach built on the hypothesis that instead of "fixing" the black box, we need to make it more transparent by developing advanced techniques that allow both students and machine learning practitioners to visualize what is learned by deep networks and how different parameters of the learning affect the learned representation and the process by which it is learned. Our overall goal is to develop practical visualization tools that help machine learning to be effectively applied to challenging but critical classification problems such as those encountered by the Navy. We address four specific challenges, (1) limited training datasets, (2) lack of explainability and debuggability, (3) adversarial inputs, and (4) shortage of expertise with machine learning in the workforce.



Professor David Crandall (upper right) discusses project details with his students in a virtual meeting.

Professor Crandall (far right) meeting with his research group.

NSWC Crane

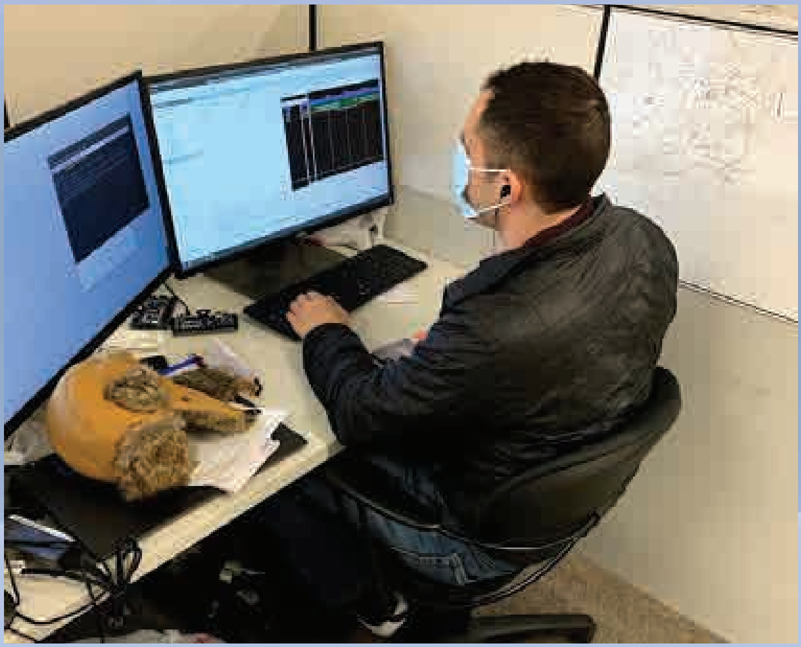
A Reverse Engineering and Physical Verification Approach to Functional Testing Tools for Field-Programmable Gate Arrays

Professor:
Andrew Lukefahr

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

Indiana University

The goal of this project is to design and build Independent Functional Testing (IFT) tool suits for Field-ProgrammableGate Array(FPGA) using a two step process. As the architectural details for many FPGAs is undocumented, the first task is to utilize reverse-engineering techniques to determine exactly 'what to test'. Next, determination of 'how to test' will lead to methodology for testing of FPGAs. Unlike traditional functional testing approaches, the designed method will rely on simple unit testing and dynamic partial reconfiguration to exercise the FPGA fabric without highly-customized and non-portable test vectors.



Professor Andrew Lukefahr's student working in the lab.

NSWC Crane

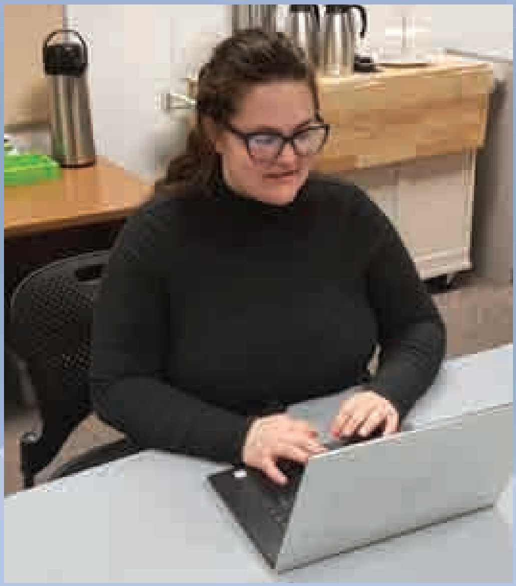
Combined Effects of Nose Bluntness and Yaw on Turbulent Transition Over Conical Nose Cones

Professor:
Eric Matlis
Aleksander Jemcov
Thomas Corke

Students:
- PhD: 1

University of Notre Dame

This work effort will investigate turbulent transition over a yawed cone at Mach 6. We will combine numerical simulations and experiments using variable nose bluntness and yaw angles to focus on the combined mechanisms of 2nd Mode and Cross-Flow instabilities leading to transition to turbulence. The two mechanisms of turbulence transition are usually considered in isolation, with the delimiter usually being the degree of yaw angle. However, little is known for intermediate yaw angles where both mechanisms are viable routes to transition, and in which potential interaction between the two instabilities might occur that impacts transition predictions based on a linear theory eN method. At hypersonic Mach numbers, turbulence transition has a critical impact on surface heat flux. This motivates techniques for transition control. 2nd mode amplification can be reduced through increased nose bluntness. Turbulent transition resulting from Cross-Flow instability can be suppressed with specifically tailored discrete roughness. Both approaches are based on linear theory predictions of each mechanism in isolation. This research is investigating conditions at which both instability mechanisms exist simultaneously. Potential interactions are being studied which will provide a framework for transition preduction of high speed vehicles of interest to the Navy and the hypersonics research community. Based on the results of these studies, we will develop mechanistic approaches to transition control. The practical impact is on reducing the thermal requirements on materials, aperatures, and sensors located on the aft portion of hypersonic vehicle nose cones.



Professor Eric Matlis' student performing calculations for experimentation.

Professor Eric Matlis' student setting up an experiment in the laboratory.

NSWC Crane

Cost-Aware Defense of Sensors-to-Decisions System against Malicious Data Attacks

Professor:
Jinsub Kim
Raviv Raich

Students:
- **Undergraduate:** 5
- **PhD:** 3

Oregon State University

Machine learning algorithms are popularly used for making statistical decisions (e.g., target detection) about sensed environment based on various sensor data streams (e.g., vision, RADAR, LIDAR, acoustic, RF sensors). Such a "sensors-to-decisions" (S2D) system has played crucial roles in various naval operations such as reconnaissance and detection/tracking of enemy units. The crucial role of S2D systems makes them appealing targets for cyberwarfare. Therefore, it is essential to understand vulnerability of an S2D system to potential attacks and equip the system with an effective countermeasure to mitigate attack impacts on decisions made by the S2D system.

In this project, we focus on data attacks wherein an adversary compromises part of sensors in an S2D system and falsifies data from the compromised sensors in order to mislead the machine learning algorithm with falsified data inputs and eventually affect its decisions. Our objectives are to develop an effective and scalable countermeasure that can make the machine learning decisions of the S2D system maximally resilient to data attacks and to develop visualization techniques that can help system operators achieve situational awareness about the ongoing attack. At the successful completion of the project, the developed techniques are expected to be able to be used for protecting various naval S2D systems against potential data attacks.

Oregon State University students discussing project details and potential experimental techniques.

Oregon State University NEEC students analyzing data.

NSWC Crane

Harnessing Quantum Correlations for Quantum Sensing

Professor:
Ram Narayanan
Matthew Brandsema

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

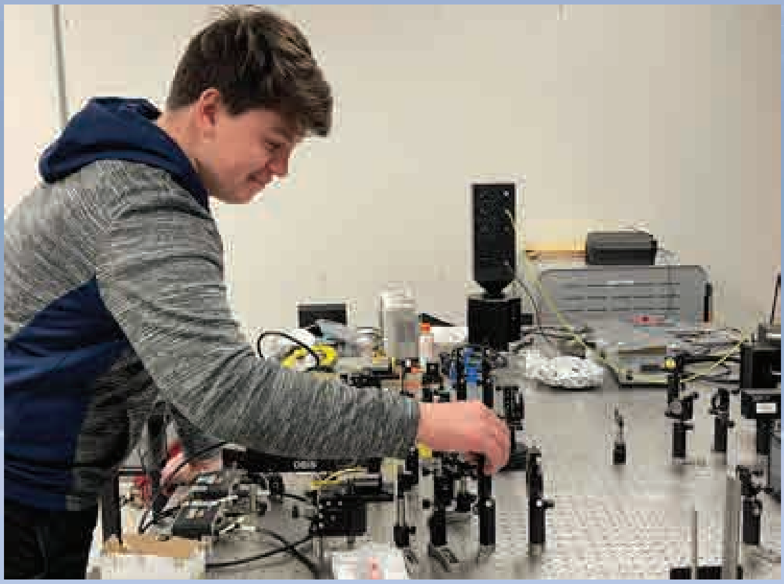
Pennsylvania State University

This project addresses the fundamental research issues related to the development of futuristic sensors for detection of targets with accuracy and high resolution by exploiting the phenomenon of entangled photons. An important justification for the proposed research is the explosive growth in the number of papers published on this topic by Chinese researchers and the need for the U.S. to maintain our technical advantage in this important field. Quantum radar is the use of quantum states of light to probe a stand-off target of interest and ascertain range, velocity, or other similar types of information. It has been shown theoretically and experimentally that utilizing the intrinsic correlations unique to entangled states yields performance gains in detection error probability, leading increased signal-to-noise ratio (SNR) in the high noise low transmissivity regime (this translates into the possibility of stealth sensing).

Much of the work related to quantum remote sensing is currently being done in the optical regime. The optical regime offers much easier experimental setups, at much lower costs. Creating entangled photons can be done in a room temperature environment, with very inexpensive laser setups. Likewise, detecting single optical photons can be done with commercial-off-the-shelf equipment and is done quite routinely. Quantum remote sensing in the optical regime is called quantum LIDAR. The experimental approach proposed to be developed to validate our theory will initially occur in the optical regime, with possible extensions into the microwave regime.

Potential Navy applications include robust approaches for detection and range estimation of targets at low signal-to-noise ratios using quantum entanglement phenomena.


Penn State University NEEC student setting up an experiment on the optical table.


Penn State University student making an adjustment for his quantum correlation NEEC experiment.

NSWC Crane

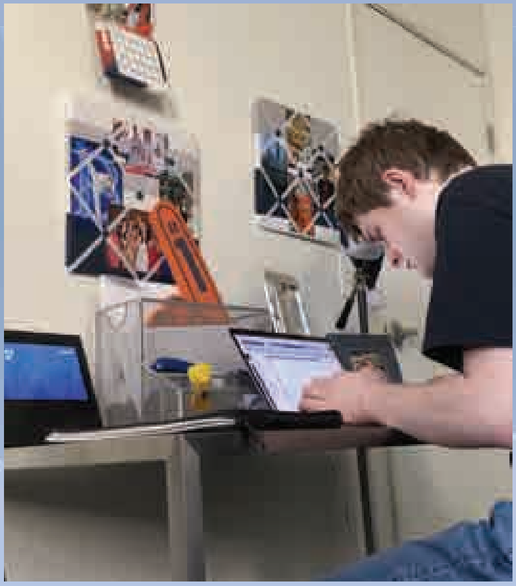
Modeling Complex Hypervelocity Flight Systems-of-Systems at the Component Scale

Professor:
Daniel DeLaurentis
Shreyas Sundaram

Students:
- Master's: 2

Purdue University

The objective of the project is to develop and/or enhance foundational theories, methods, and techniques for advanced modeling and simulation of complex hypervelocity flight systems-of-systems at the component scale. The effort will focus on Guidance, Navigation, and Control (GNC) sub-systems, but with relations to other vehicle sub-systems included. The large diversity of interacting, multidisciplinary components, including embedded computers, sensors, actuators, batteries, fuel tanks, engines, and flight controllers, requires a formalism that is able to capture the complex dynamics of the interactions. Further, the significant Size, Weight, and Power (SWaP) constraints of these systems requires an ability to perform vehicle-level technological trades that optimize speed and effectiveness for integration of novel subcomponent technologies. The assessment of risk at the overall vehicle capability level due to component performance degradation (or failure) will also be addressed. All of these considerations directly support the needs of Naval applications of hypersonic vehicles, for example conventional prompt strike. The technical approach will center on enhancing the Systems Operational Dependency Analysis (SODA) by leveraging and introducing the formalism of interconnected hybrid systems into the modeling and analysis of complex hypersonic vehicles, and thereby understand the implications of the interdependencies for the functioning and behavior of the overall system. A series of simulation experiments based on well-defined hypotheses will be conducted once the appropriate models are created in order to produce evidence on whether these approaches are in fact promising for the goal of optimal technology infusion for hypervelocity systems.



Purdue University NEEC student analyzing Hypervelocity Flight System data.

Purdue University NEEC student developing models for Hypervelocity Flight System experimentation.

NSWC Crane

Visualization of Repair Operations Management for Networked Systems Resilience

Professor:
Chenn Zhou
John Moreland
Kyle Toth

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

Purdue University Northwest

This project is focused on developing methods for intuitive interactive visualization for decision making related to computer network stability and the repair agents. Computer Networks are collections of nodes, such as computers, routers, and switches connected by a variety of wired and wireless signals. In military and civilian networks, the health of the network as a whole depends on the functionality of its individual components. If a node is impeded due to cyber or physical attack, repair agents may be required to repair individual nodes, head off cascading failures, and ensure the overall stability of the network. Previous work has developed methods to optimize the number of repair agents and locations of repair agent depots with relation to various network configurations. However, the application of these methods to real world computer networks can be difficult to process and understand for human decision makers. The current research is developing a tool for interactive visualization of the repair agent optimization methods to enable intuitive understanding and improved decision making related to network resilience.

Purdue Northwest NEEC student developing a tool for interactive visualization for repair agent optimization.

Purdue Northwest students discussing visualization approaches for network repair agents.

NSWC Crane

HACK RFML

Professor:
Alan Michaels
William "Chris" Headley

Students:
- Undergraduate: 35
- Master's: 3

Virginia Tech

In recent years, research in other deep learning modalities (images, audio, video, natural language processing, etc.) have shown that deep learning solutions are vulnerable to adversarial machine learning techniques. Adversarial machine learning can typically be broken into three primary areas of research, namely evasion attacks, poisoning attacks, and software/hardware attacks. Evasion attacks utilize intelligently crafted perturbations on the input to the deep learning algorithm to lower their performance. Poisoning attacks aim to attack the deep learning training process through injection of faulty training data or labels. Finally, software/hardware attacks target the deep learning frameworks or specific hardware implementations to lower their performance.

In this undergraduate and graduate student driven research effort, we focus on how evasion attacks and software attacks impact the performance of radio frequency machine learning (RFML) systems trained to perform spectrum sensing tasks. Through understanding the efficacy of these attacks, the students also research ways to harden systems against these attack vectors.

Understanding the vulnerabilities of state-of-the-art RFML systems is fundamentally important for the Navy as it begins to investigate and deploy RFML based spectrum sensing solutions.

Professor Alan Michaels discussing experimental data with Va Tech NEEC students.

Va Tech NEEC students working on the HACK RFML project.

Assisted Model-Based Systems Engineering (A-MBSE)

Professor:
Alejandro Salado

Students:
- **Undergraduate:** 14
- **Master's:** 1
- **PhD:** 1

The University of Arizona

We are developing a virtual engineer that helps the human engineer in modeling problems. Specifically, the virtual engineer, called Houston, evaluates models created by the human engineer and identifies potential modeling gaps using a central repository of knowledge. The repository contains rules and other guidelines derived from standards, expert opinion, and project evolution. By doing this, the virtual engineer does not only leverage the higher computational ability of modern computers, but can truly leverage the collective wisdom of an organization. As a result, problem formulation efforts are expected to take less time and be more comprehensive, reducing the risk of missing requirements important to the success of the systems developed by the Navy.

University of Arizona

NSWC Dahlgren

Improving Virtualized Data Center Resource Efficiency Using Dynamic Container Placement Strategies

Professor:
Emmanuel Arzuaga

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

University of Puerto Rico Mayaguez

Cloud Computing has become the first layer in the design and deployment of an increasing number of applications. This work studies challenges in performance and power consumption of containerizing virtual machines (VMs) in a cloud setup, focusing on factors affecting resource efficiency at the container-VM integration layer, mechanisms to handle containerized VM placement, and dynamic containerized VM placement policies that can better manage a resource demand environment, such as combat systems.

The resource usage policy for the virtualization platform being used is crucial in a modern datacenter environment. In the container case, resource usage decisions are typically performed statically (at container start), limiting its execution to a single assigned node and the amount of resource efficiency that can be achieved at a particular time. This model might not provide the tools to improve resource efficiency if a containerized VM environment is desired. This work: 1) studies the different factors that affect resource efficiency at the container-VM integration layer, 2) analyzes the mechanisms to handle containerized VM placement within a datacenter (vertical) and between datacenters (horizontal), and 3) develops dynamic containerized VM placement (DCP) policies that can better manage a dynamic resource demand environment such as combat system workloads.

University of Puerto Rico - Mayaguez

Dielectric Breakdown in High Voltage Power Systems

Professor:
David Alan Wetz Jr.

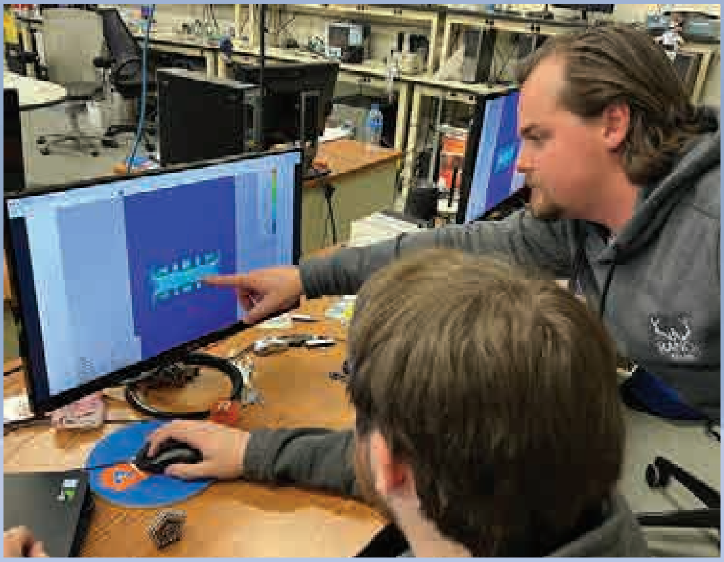
Students:
- **Master's:** 1
- **PhD:** 4

University of Texas at Arlington

To field directed energy (DE) systems aboard the future fleet, they will rely heavily on the operation of several electronic stages to be successful and all of them must perform reliably in demanding and changing environmental conditions. These stages include, but are not limited to, the prime power supply, power electronic voltage regulator, pulsed power supply, and the load.

Over the last several decades, a great deal of emphasis has been placed on designing the pulsed power supply and the load, but little emphasis has been placed on how the systems will be powered aboard mobile platforms. In laboratory settings, researchers have relied upon grid-tied power supplies that are robust and 'always' on at the ready. In shipboard applications, it is generally assumed that engine-generator sets, powered by some sort of fossil fuel, will supply power throughout the ship. In recent years, there has been increased emphasis placed on studying how engine-generator sets should be sized, what their output voltage should be, how their windings should be configured, how they should be rectified when the loads demand DC voltage, how they should be buffered with electrochemical energy storage, how to distribute them throughout the ship, and finally, how to monitor and control them reliably.

Zonal architectures like the one proposed by Norbert Doerry are being considered in which the ship is divided into discrete zones, each of which have their own engine-generator sets that are regulated and interfaced with dual medium-voltage-direct-current (MVDC) bus. The voltage of the MVDC bus could be as high as 20 kV with many still considering what is best. Within each zone, there might be DC loads that require a 1 kV bus and it is feasible for engine-generator sets to be used and rectified directly to supply them. Both the engine and motor dynamics, respectively, under transient loads must be better understood before this can be achieved. Further, the impact these dynamics have on power quality and how rectification is achieved are also not perfectly understood.



PhD students evaluate an electric field simulation of an epoxy dielectric sample.

PhD students load an epoxy dielectric sample into the pulsed load section.

NSWC Dahlgren

Electrical Dielectric Breakdown of Insulators Used in High Energy Pulsed Power Systems

Professor:
David Alan Wetz Jr.

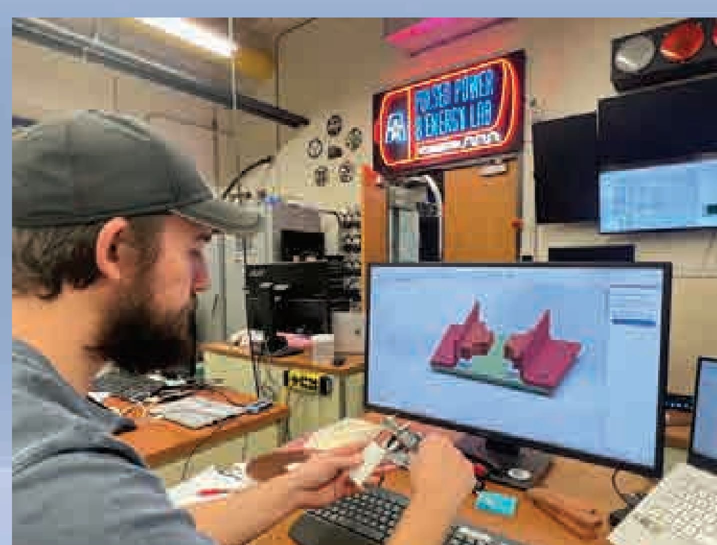
Students:
- Undergraduate: 1
- Master's: 1

University of Texas at Arlington

The high voltage community faces many challenges as they move towards fielding directed energy systems onto mobile platforms. One of those challenges is preventing dielectric breakdown that occurs when an insulator fails, and the positive and negative conductors can contact each other through an arc discharge. The arc can form through the air or along the surface of the insulator and either can be catastrophic. Nominal operational voltages in the 1 - 50 kV range are to be used and it is conceivable that transients much higher may be generated.

In many high voltage systems, including those used by the US Navy, plastic and epoxy materials are used, some of which are reinforced with fiberglass. The manufacturing process of these insulators may introduce voids or inconsistencies within the material that compromise its dielectric strength, especially across the surface. The embedded fiberglass layers have many sharp points exposed that create electrical field enhancements that weakens the material's dielectric strength. The edges of these materials, especially after they are machined, may expose sharp points on the surface, altering the electric field across the surface and weakening the surface flashover potential. The presence of moisture, dust, debris, and especially hydrocarbons on the surface only further degrades the surface flashover potential. NSWC Dahlgren has invested considerably in developing new types of electrical insulators. The dielectric flashover of these insulators has not been well studied. A better understanding of surface flashover phenomena and potentials in shipboard environments must be studied to reduce risk of electrical breakdown within a fielded high voltage system. The present design criteria used by high voltage engineers is conflicted and understanding of true performance (without margin) needs to be understood. UL 840 is one standard used routinely but it is very vague and not well understood. How the standard was developed and what margin is built into it is unclear.

Masters student installs the physical flashover test stand into a dielectric hi-pot tester for experimentation.



Masters student works on a solid model of this surface flashover test stand.

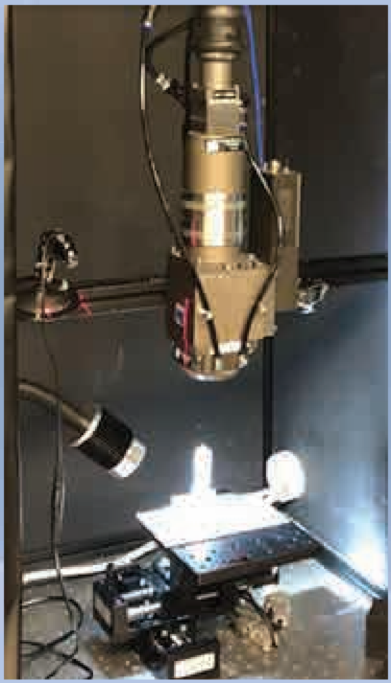
High Power Laser Studies of Thermal Oxidation and Ablation Properties of Ceramic Matrix Composite Materials for Hypersonic Applications

Professor:
Mool C. Gupta

Students:
- Master's: 1

University of Virginia

The objective of the research is to provide a scientific understanding of oxidation and ablation properties of ceramic matrix composite (CMC) materials used in hypersonic vehicles, so that they can be operated for an extended period of time and have high reliability. Thermal protection systems are required for ballistic re-entry to hypersonic cruise vehicles as the leading edge could encounter temperatures of over 2000 deg C, corrosive plasma from the atmosphere leading to severe oxidation, and extreme heat fluxes. A complex experimental setup is required to generate such high heat fluxes and evaluate the material oxidation and ablation rates. We propose a laser oxidation and ablation method to evaluate the hypersonic material degradation rates and the measurement of interface temperature. The high-power laser method is a much simpler method, and a fundamental understanding of the oxidation and ablation process can be achieved. The proposed experimental laser oxidation and ablation results will allow the validation of models and easy screening of different test materials for future performance improvement. The generated data would provide the limitations of current materials systems. The research also provides data for the development of a shield against laser threats to hypersonic vehicles and other objects. The Navy's goal of rapid reach and global targeting can be achieved by hypersonic flights by extending the travel distance and reduction of transit time. The ability to launch projectiles at hypersonic speeds is important to the Navy, and materials challenges must be overcome. So, providing surface ships and submarines with hypersonic capabilities would greatly enhance Navy striking capabilities. To advance hypersonic vehicle technology, further research is needed on ultrahigh temperature materials and thermal protection systems. The project will provide educational training to students in the area of lasers, optics, and photonics and will develop stronger research collaboration with Dahlgren engineering staff, which will allow further enhancement in research and educational activity.



Students at the University of Virginia incorporate the laser oxidation and ablation method, utilizing a 4000-watt laser set up for materials studies.

UVA students discuss high power laser experiments.

NSWC Dahlgren

Deep Learning based Target Tracking and Assignment for Cooperative Swamp Defense

Professor:
Ju Wang
Wookin Choi

Students:
- **Undergraduate:** 4
- **Master's:** 2

Virginia State University

We investigate how novel AI-backed architecture can support future cooperative combat of unmanned and manned warships against swamp aerial threats. We address two crucial challenges in anti-swamp defense: (1) target tracking and (2) target assignment. For target tracking, we propose a CNN architecture with a multi-frame regression layer to predict high-accuracy 6D pose estimation. For the target assignment problem, we will investigate a Reinforcement Learning policy network that utilizes the target 6D pose estimation to calculate an optimum solution.

VSU student working with K-12 students during a STEM summer camp.

VSU student participates in a university hosted STEM outreach summer camp for K through 12th grade students.

Local students participate in a VSU hosted STEM outreach summer camp.

NSWC Dahlgren

Secure and Scalable Systems Software: Verification of Safety and Security Properties of Assembly Code, OS Driver Randomization, and Extension of Popcorn Linux Subsystems

Professor:
Binoy Ravindran

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

Virginia Tech

The goals of this NEEC project include developing a methodology for verifying security properties of software systems, including common forms of software vulnerabilities such as memory corruption attacks and code reuse attacks, and verifying that their defense mechanisms continue to satisfy software's functional requirements. The project also aims to develop techniques that improve the security of potentially vulnerable subsystems of the Linux operating system, such as device drivers by continuously randomizing their locations in memory. In addition, the project aims to optimize subsystems of Virginia Tech's Popcorn Linux operating system that provides an easy-to-program software infrastructure for emerging heterogenous computing architectures. Additional goals include training and mentoring students in the underlying computer engineering sub-disciplines, including software verification, operating systems, computer architecture, concurrency, and compilers.

Virginia Tech PhD students participate in the NEEC grant project with Professor Binoy Ravindran from the Electrical and Computer Engineering Department.

Virginia Tech Professor Binoy Ravindran poses with PhD students in computing engineering, in front of a NEEC project poster.

NSWC Dahlgren

Characterization, Analysis, and Simulation of Unsteady Aerodynamics and Flight Trajectories for Unstable or Off-Nominal Free-Flight Bodies

Professor:
Wade W. Huebsch
Pat Browning
Chris Griffin
Piyush Mehta
Jason Gross

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

West Virginia University

Naval test and evaluation programs involving advanced threat missile systems require digital simulations of non-traditional flight modes. These non-traditional flight modes may be due to intentional aerodynamic design or by a damaged state. This results in scenarios where you have things like unstable tumbling bodies, characterized by severely non-linear, separated, and unsteady flows or damaged platforms that have off-baseline aerodynamic characteristics. These simulations must accurately model these types of scenarios: a) replicate the actual rotational rates and fundamental character of the tumbling motion since these directly affect the signatures of the object that are presented to the weapon system as well as b) the probability for the damaged threat to reach its intended target.

These simulations should be sufficiently generalized to span across multiple threat system variants, various states of damage, and multiple phases of flight to allow their ready use with evolving threats without requiring substantial rework, and be aligned with current test assets used in Navy Operational Test (OT) testbeds. Further, they must be integrated and tested in the existing Navy testbed architectures, and then possibly in an at-sea environment utilizing software-in-the-loop systems.

Our strategy is to conduct a three-element effort consisting of experiments, simulations, and analyses to develop a robust simulation-based solution for significant events and object motions consisting of tumbling and/or damaged bodies, characterized by severely non-linear, separated, and unsteady flows.

WVU PhD Graduate student prepares to launch a free-flight block to test and gather rotational experimental data in support of a machine learning application.

NSWC Dahlgren Division Scientist Graham McConnell and a WVU Graduate student work to install a missile model in preparation for wind tunnel testing at WVU.

NSWC Indian Head

In-Ear Wearable Device (EWD) For Predicting Warfighter Readiness-HDTRA CB10787

Professor:
Sangram Redkar

Students:
- Master's: 2
- PhD: 3

Arizona State University

JSTO-sponsored government partners are collaborating to build and test a customizable In-Ear Wearable Device (EWD) to detect the onset of changes in a Warfighter's health state through Autonomic and Bio-Chemical (ABC) signatures such as heart rate, blood oxygen level, and glucose. Development of algorithms for physiological monitoring and adverse event sensing will be programmed onto the EWD and paired with data storage to provide remote monitoring capability via ATAK compliant wireless data transmission. Testing of the EWD performance under a variety of simulated environmental conditions will verify performance of the EWD and inform system improvements.

Schematic of device design.

Students working.

Determination of the Effects of Thermal and Mechanical Stress on PBX Binder Materials

Professor:
James E. Patterson

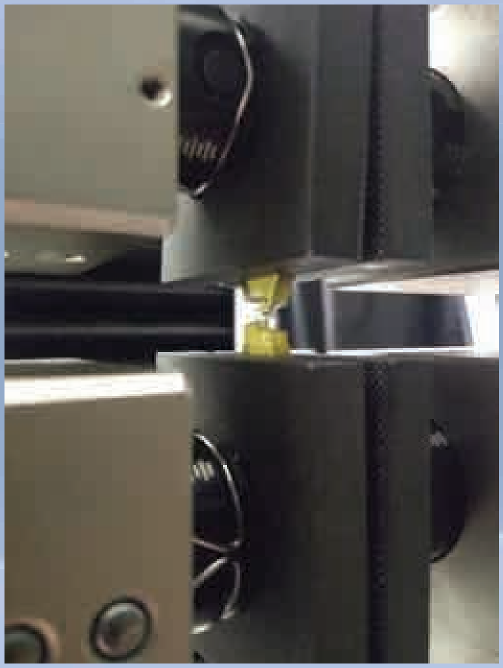
Students:
- Undergraduate: 9
- PhD: 4

Brigham Young University

As part of routine handling, fabrication, and storage, PBX materials are subjected to thermal and mechanical stress. These stresses and normal aging can affect the material state of both the HE and binder components, as well as the HE/binder interface. As a result of stress and aging, PBX performance may be altered, perhaps to the point where the materials are no longer suitable for their intended purpose. Safe storage and handling of PBX materials may also be compromised by these material changes. Our central hypothesis is that the effects of aging, as well as thermal and mechanical stress, ultimately have their roots in changes to the molecular structure of the binder, the HE, and/or the binder/HE interface. Thus, developing a detailed understanding of the material response to these stresses requires investigations that can probe both bulk and interfacial molecular properties.

The primary purpose of the proposed work is to identify the chemical, structural, and interfacial changes that take place in PBX materials as those materials age and are subjected to thermal and mechanical stress. The results of this work will not only improve our fundamental understanding of these materials, but also allow for the development of spectroscopic screening methods that can be used to assess the quality and suitability of PBX stockpiles for safety and performance.

Our work has focused on fabrication and characterization of hydroxyl-terminated polybutadiene (HTPB), a common elastomeric binder material. We have developed methods to spectroscopically investigate the response of these materials to mechanical stress and simulated aging. Our main spectroscopic techniques include Raman microscopy and vibrational sum-frequency generation. Recently, we have developed the capability of performing these measurements while the samples are subjected to tensile deformation; previously we could only probe samples after they had been deformed and relaxed. This new capability makes possible in situ studies of these materials and their molecular-level response to deformation and mechanical stress.



Sample after completed mechanical test.

Test fixture during set up and adjustment.

NSWC Indian Head

Characterization of Navy Probes for Temperature and Species Measurements in Shock Tubes

Professor:
Subith Vasu

Students:
- PhD: 1

University of Central Florida

Energetic materials and propellants (EMs) are of paramount importance to the Navy's warheads, hypersonic systems, rockets/missiles, and other propulsive systems. EMs must be adaptable in size to fit a family of delivery systems, contain sufficient energy to defeat the target, have the capability to fly further and faster while being insensitive munition compliant and affordable. Accurate characterization of temperature fields within blasts and fireballs produced by EMs and explosives is critical to characterizing weapons systems' lethality and effectiveness for a range of applications, including counter-WMD operations. Obtaining accurate, time-resolved, localized temperature measurements within a fireball, however, poses many challenges due to the harsh nature of the environment. Problems to overcome are maintaining adequate sensitivity over the large range of temperatures to be measured (ranging from 300 – 3000 K), having sufficient signal in optically thick, particle-laden flows, and surviving high pressures from the blast wave. Furthermore, for a temperature diagnostic to be maximally informative, it must provide fast time-resolution (~ µs). Navy labs have developed various intrusive and non-intrusive techniques for measuring flow field parameters in such harsh environments. Detailed and accurate characterization of temperature diagnostic probes is crucial in this effort. UCF will use their state-of-the-art shock tube and detonation tube setups for characterizing the performance of probes used in Navy efforts under high temperature and pressure conditions. Shock tube provides an ideal platform for simulating high-temperature conditions experienced in real events. UCF will also cross-validate the performance of Navy probes with in-house absorption and schlieren diagnostics. The research will also enhance student training capabilities at the University of Central Florida, one of the largest Hispanic Serving Institutions in the country with more than 70,000 students, in characterizing the performance of explosives and propellants for weapons systems. It will directly contribute to Ph.D. dissertations and undergraduate honors theses and provide a future DoD workforce pipeline.

Test setup used in experiments.

Tube used for testing.

NSWC Indian Head

Ultrafast Detection and Imaging of Underwater Blasts

Professor:
James Michael

Students:
- Undergraduate: 1
- PhD: 2

Iowa State University

Imaging through particle- and bubble-laden water remains a challenging problem for testing and evaluation of energetic systems due to the nature of underwater explosive tests. The test environments typically consist of meter-scale bodies of water which contain suspensions of particulate media and bubbles—both leading to significant scattering and attenuation of propagating light. Characterization of the explosive breakout and vapor-liquid interface during the initial explosion requires measurements with limited optical access (i.e. single-side detection) and sufficient temporal resolution.

Underwater explosive.

NSWC Indian Head

Production and Characterization of Ni-Al Reactive Composites by Cold Spray Deposition

Professor:
Grant Crawford,
Lori Groven

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

South Dakota School of Mines and Technology

SOUTH DAKOTA MINES
An engineering, science and technology university

Metal-based reactive composites have significant potential for use as structural energetic materials and advanced blast materials. Unfortunately, adoption of these materials for energetics applications has been limited by the elevated ignition temperature and high impact energies required to initiate the combustion reaction. To address this challenge, the South Dakota School of Mines and Technology is investigating the use of cold spray technology to deposit nanolaminate-based nickel-aluminum powder particles to produce dense, energetic composite structures with good mechanical properties and increased reaction sensitivity.

Through this project we will establish the relationship between cold spray processing, the resulting composite microstructure, and both the reaction kinetics and reaction mechanisms of nanolaminate-based nickel-aluminum composites. The project is currently focused on the development of effective and efficient methods for the processing of nanolaminate nickel-aluminum powders using a two-step high energy ball milling procedure. We will next use cold spray technology to produce energetic composites. The microstructure and phase composition of the composites will be characterized using advanced materials characterization tools and the energetic behavior will be evaluated using both thermal (heat source) and mechanical (impact) reaction initiation. If successful, the project will establish a new method for additively manufacturing highly sensitive, structural energetic materials for use in a variety of critical defense applications.


Data monitoring in progress.


The mill used for experiments.

NUWC Keyport

Empirical Human Performance Modeling to Inform the Design of Performance Support Applications

Professor:
Monifa Vaughn-Cooke

Students:
- Undergraduate: 3
- PhD: 2

The University of Maryland

The Hybrid-Systems Integration and Simulation Laboratory at the University of Maryland will investigate the influence of mixed reality system design specifications on human performance outcomes for unmanned vehicle controls. Physical input modalities (buttons, switches, etc.) will be integrated with virtual screen displays to determine the most effective mixed reality design options to support operator performance for decision-making activities with varying cognitive complexity and sequence. A unique experimental facility (UMD's Virtual Reality CAVE) will be used to immerse participants in multi-modal simulated unmanned control environments, where physical objects will be integrated into a virtual space. An empirical study will be conducted with operators, using a combination of indirect (neurophysiological workload) and direct (perceived workload, timing, accuracy) measures of cognitive workload to determine the impact of system design considerations on human performance. The results of this research will inform mixed reality design for control interfaces by reducing the risks associated with cognitive workload and improving system safety. In addition, recommendations for standardized metrics will be defined to integrate into system design validation activities to determine if customized designs are acceptable.

Student researchers are integral to the proposed activities. The research will utilize the laboratory's existing K-12, undergraduate, and graduate student pipeline to aid in simulation development, experimental testing, and data analysis activities. The ultimate goal is to create a pipeline of students who are trained through formal and hands-on experience to design, evaluate, and implement human-centered systems across the Navy.

Students in the HSIS lab.

NEEC student testing.

Coordination of a Multi-Platform UUV/ASV System: Low-Cost Experimental and Simulation Test Environment with Fuzzy Logic Based (AI) Autonomy Evaluation

Professor:
May-Win Thein
Co-PI: Yuri Rzhanov

Students:
- **Undergraduate:** 22
- **Master's:** 3
- **PhD:** 5

University of New Hampshire

The development of autonomous marine vehicles, particularly the coordination of autonomous UUVs, continues to be in high demand. One of the significant challenges in the development of autonomous marine vehicles is developing the ability of the vehicle to perceive its environment for executing its mission, including self-localization, obstacle avoidance, area/mapping, particularly for the purposes of obstacle/collision avoidance. For this purpose, the University of New Hampshire (UNH) is developing a low-cost test bed environment with three research goals: (1) to develop a simulation testing environment to analytically observe and predict UUV perception capabilities and its performance on overall system autonomy; (2) to further develop an experimental multi-vehicle test platform (for laboratory and field testing) in which (2A) UUV perception and autonomy capabilities can be physically tested and (2B) a low-cost sensor system will be designed and implemented to enable autonomous coordination of multiple UUVs; and (3) to develop an Artificial Intelligence (AI) based metric system (via Fuzzy Logic and Fuzzy Set Theory) to numerically evaluate vehicle autonomy performance.

The simulation test environment will be developed to test and compare autonomy algorithms based upon user-defined mission criteria and canonical autonomy subtask capabilities. Previous automated path planning techniques (from previous NEEC grant results) will be further developed and implemented. Fault Detection and Isolation/Mitigation (FDI/M) techniques will developed (with the aid of redundant sensor banks) to not only improve vehicle perception capabilities, but to also improve the quality of sensor measurements needed for reliable automatic feedback-based vehicle control.

Students testing the vehicle.

Laboratory testing.

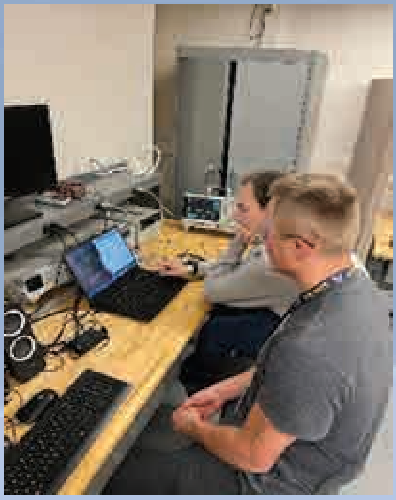
Advancing Self-Localization and Intelligent Mapping (SLIM) for Swarm of Autonomous Unmanned Underwater Vehicles using Machine Learning

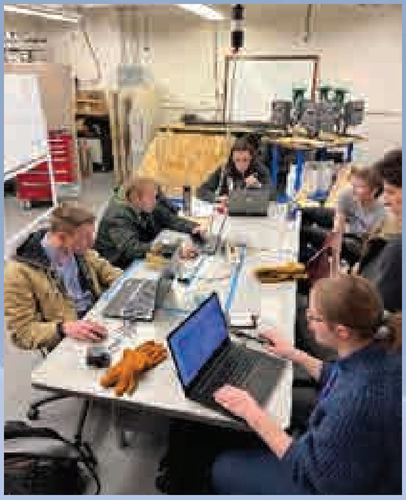
Professor:
Hadi Fekrmandi
Randy Hoover

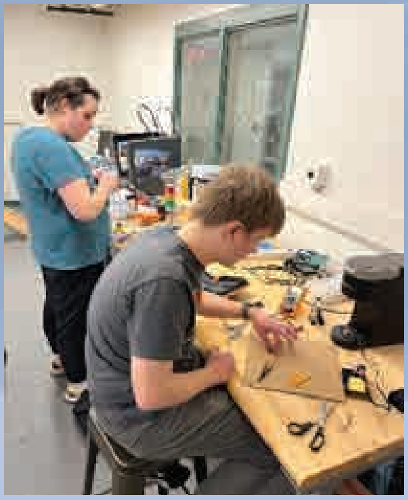
Students:
- **Undergraduate:** 10
- **Master's:** 3
- **PhD:** 2

South Dakota School of Mines & Technology

Multi-agent systems (MAS's) have received significant attention from the research communities in multiple important application domains including computer networks, computational modeling, cities and environments, smart grid, and robotics. The Navy's specific problem in undersea autonomous operations arises due to a lack of a global positioning service and the need for improved robot perception in the missions that autonomous undersea vehicles (AUVs) need in order to operate longer durations under sea. The main MAS problems are distributed coordination, and decision making. The objective of the Simultaneous Localization and Intelligent Mapping (SLIM) research is advancing the state-of-the-art of autonomous robot perception in environments with relatively few features through a multi-agent systems approach. During the 'self-localization' phase of the NEEC SLIM project at South Dakota Mines, we developed a distributed framework for state estimation that is a potential key factor for consideration to improve robot perception and address both the reliability, scalability and connectivity due to communication link failure for collaborative AUV missions of the Navy. There are various architectures that allow multiple agents to perform state estimations while operating in a dynamic network. These include (a) a centralized architecture, (b) a connected architecture, and (c) a non-centralized, partially connected architecture. In a remote undersea domain, using a centralized framework can compromise a mission by introducing a single point of failure.







NEEC Fellows and RoboBoats at Advanced Intelligent Mechatronics (AIM) Laboratory.

NUWC Keyport

Mechanical Obsolescence Management: Risk-Based Analysis and Prediction

Professor:
Christina Mastrangelo

Students:
- Undergraduate: 9
- Master's: 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, this project is working toward a proactive strategy to obtain a likelihood for an end-of-life event such that a solution prior to actual obsolescence may be implemented.

The goal of this project is toward a more proactive obsolescence management approach by looking at the equipment 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. Of particular interest is the post-procurement part of the life cycle costs (redesign, re-hosting and re-qualification) because these costs may contribute as much or more to the total life cycle cost as the initial cost of hardware and software. The team is gathering data on a variety of mechanical part types and testing the predictive analytics developed for COTS and electronic parts on this part type for implementation into NUWC Keyport's Obsolescence Management Information System (OMIS™).

Data Analytics team meeting.

Data Analytics team meeting.

NUWC Keyport

Development of Collaborative Human-Robot Systems for Inspection and Repair Tasks in Tightly Constrained Spaces

Professor:
Ashis G. Banerjee
Santosh Devasia

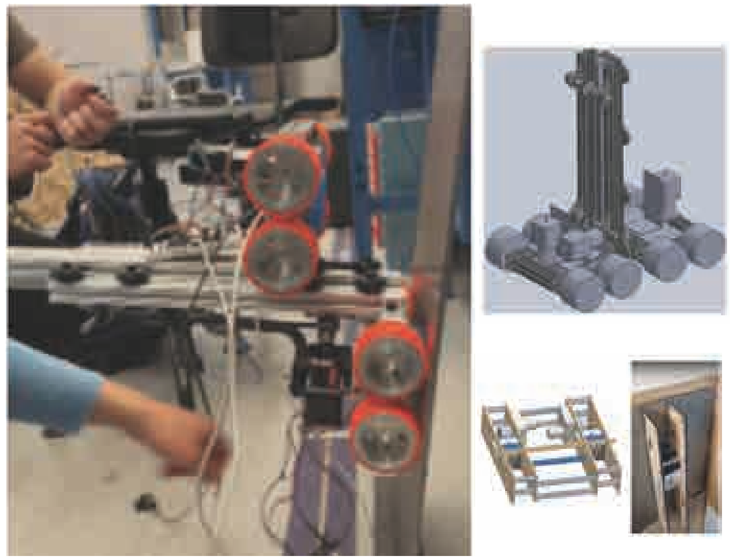
Students:
- Undergraduate: 10
- Master's: 2

University of Washington

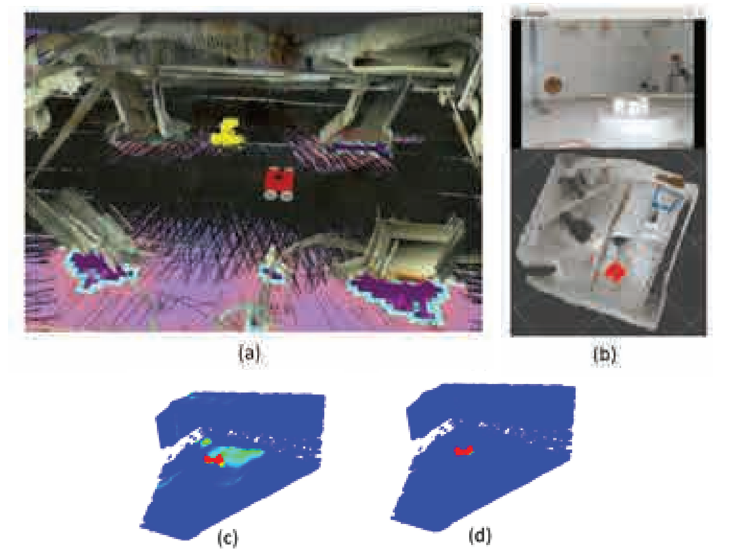
A variety of Navy shipyard inspection and repair operations require hazardous and/or labor intensive tasks that are carried out in tightly constrained spaces. Examples include coating removal, welding and painting, enclosed tank and void repair, and internal piping inspection. It is hypothesized that mobile robots may be immensely useful, in terms of both safety and reliability, to perform these tasks in collaboration with humans.

However, certain key technical challenges need to be addressed to realize such mobile robotic operations. While the robots are typically equipped with a multitude of sensors and actuators that are quite accurate, they are not necessarily very precise. Moreover, each sensor and actuator type encounters difficulties for certain kinds of measurements and actions, respectively. Hence, probabilistic models are being used to recursively estimate the states of the robots and their workspaces based on the continuous sequences of measurements and actions. The robots also encounter difficulties in successfully completing new tasks, particularly in unknown spaces that have not been explored before. Consequently, simultaneous environment mapping and robot localization methods have been developed, followed by collision-free robot navigation planning.

Based on these developments, we have focused our research efforts on the problem of robust detection of foreign object debris (FOD), which might have been left behind inadvertently in the constrained spaces during prior installation or maintenance operations.



Magnetically actuated wall climbing robot designs and prototypes developed by two UW Mechanical Engineering senior undergraduate capstone project teams.



Visual simultaneous localization and mapping (SLAM) inside a poorly-illuminated confined space (water tank) in a marine vessel. (A) SLAM in progress for a ground robot in a simulated tank. (B) SLAM in progress for a robot in a physical mock-up tank. (C) Anomaly (power drill left behind in the tank by mistake, as shown in yellow) detection by training on a nominal CAD model. (D) Anomaly detection by training on an empty tank point cloud map.

NUWC Keyport

Durability of Additive Manufactured Polymers and their Composites in Prolonged Marine Environments

Professor:
Dwayne Arola

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

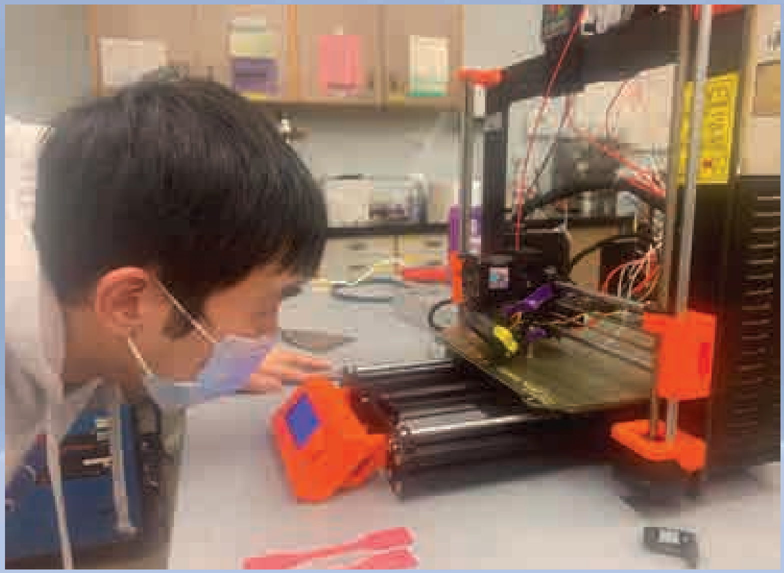
University of Washington

Additive manufacturing (AM), also regarded as 3D printing, enables the fabrication of near-net-shape components directly from 3D computer-aided design (CAD) data. This method of manufacturing offers unparalleled flexibility to the design engineer and very short times to manufacture, which enables increased responsiveness. It is revolutionizing the design and method of manufacturing in many industries and for nearly all classes of materials. AM processes could ignite transformational changes in the development of next-generation autonomous and unmanned underwater vehicles, which are strategic to the navy.

In applications of AM components, performance standards are generally defined by the mechanical properties of the materials and the expected variability in their properties. In marine and undersea applications, the mechanical properties of AM parts are highly relevant, but there are unique concerns involving material degradation resulting from prolonged marine exposure, which may involve biofouling, hydrolysis, etc. In addition, newly developed continuous fiber composites for AM could serve the marine industry by enabling new levels of performance. However, there is limited understanding of how the microstructure of polymer composites influence the potential for degradation under prolonged marine exposure.

The overall objective of this NEEC effort is to investigate the effects of prolonged marine environment exposure on the durability of AM monolithic and reinforced polymers, as well as their hydrodynamic characteristics. The work involves three specific aims, which have been designed to increase confidence in AM of polymers and polymer composites for marine applications. The results of this effort will identify the most appropriate polymer systems for marine environments and provide new understanding concerning their durability specific to AM processing.

NEEC student testing materials.



NEEC student lab testing.

NUWC Keyport

Magnetic Induction Communication Unmanned Underwater Vehicles

Professor:
Murari Kejariwal

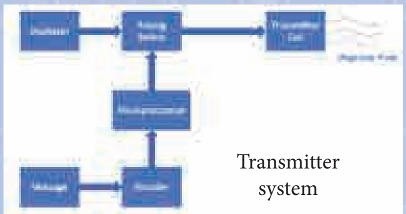
Students:
- Undergraduate: 3

Washington State University

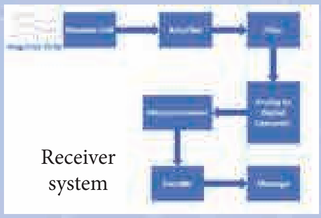
Communication via magnetic induction is a relatively unexplored yet promising alternative to conventional communication media, particularly for applications in environment—such as underwater which poses challenges to traditional communication methods. This project is undertaken under the sponsorship of Naval Undersea Warfare Center (NUWC) Division Keyport. The goals of the project are to:

(i) Characterize the communication channel via data collection and analysis in (a) free space, (b) fresh water, (c) sea water; and (d) air to water and water to air media; keeping in mind the application for unmanned underwater vehicles; and
(ii) To design, implement, and demonstrate proof of concept of a magnetic induction communication system for undersea applications.
This project is a continuation of work done by previous WSU student group who worked for their senior capstone design project.

The present system is powered by sealed lead acid batteries and can easily be incorporated in any unmanned underwater vehicle. The system level block diagrams for transmitter and receiver are given below:

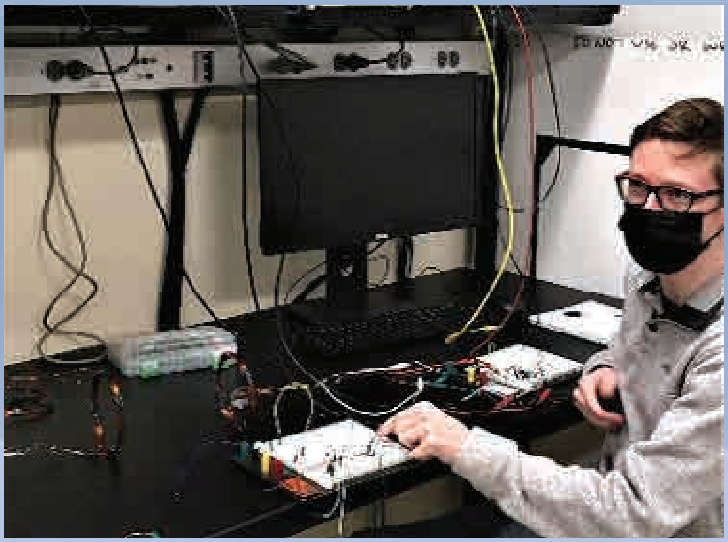


Transmitter system

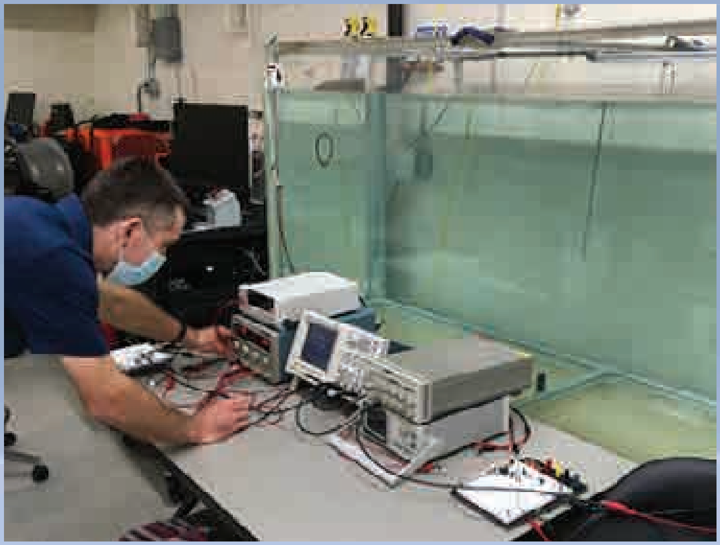


Receiver system

This group has characterized the communication channels in free space and fresh water. They are working on the characterization the communication channel in sea water, and air to water and water to air communication.



BSEE students working the project using magnetic coils.



BSEE students working the project using magnetic coils.

NUWC Newport

Improved Robot Autonomy Using Neuromorphic-Based Stochastic Computing

Professor:
Scott Koziol

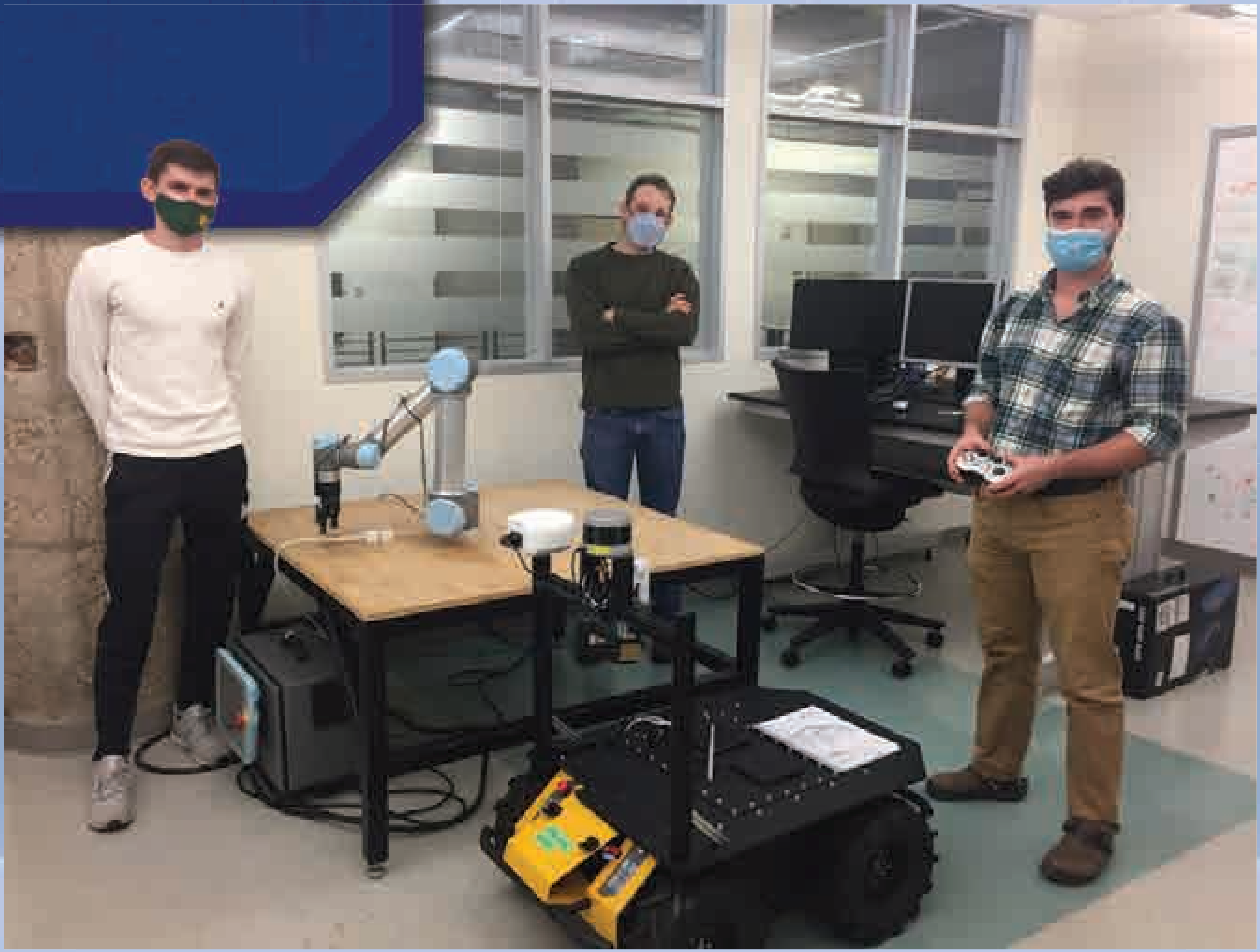
Students:
- **Undergraduate:** 2
- **Master's:** 2
- **PhD:** 2

Baylor University

The objective of this work is to use novel computing techniques to provide improved autonomous robot capabilities by fundamentally changing the way onboard computation is performed.

The scope of this project is circuit and algorithm co-development, computer simulation, and circuit hardware experiments. The objective is to assess the performance of a bio-inspired stochastic computing method. The proposed method's computation capabilities will be compared to standard digital implementation methods (e.g. image processing,neural networks).

The system level problem being addressed is to provide better onboard computation systems for small autonomous robots performing missions such as surveying. This is important because onboard computation is limited due to size and power constraints, and computing is a critical capability for autonomous systems performing these missions. Potential applications are for integration into systems to improve navigation, acoustic localization, or underwater sound tracking in challenging environments.



Three Baylor University NEEC graduate students in the Neuromorphic & Robotic Systems research lab. Their Baylor faculty advisor for the project is Dr. Scott Koziol and the NUWCNPT mentors are Dr. John DiCecco and Dr. Eugene Chabot. The project involves commercial FPGA circuit boards, as well as custom electronics developed in the lab.

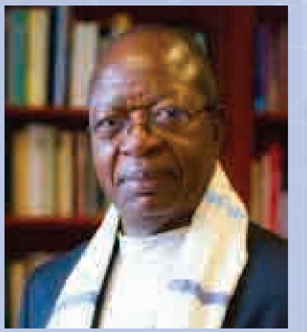
Advanced Mathematical and Computational Methods for Probability Densities Evaluations and Information Measurements Involving AI/Ml

Professor:
Bourama Toni

Students:
- PhD: 1

Howard University

Our project is PhD-grade, and 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

Localization, Tracking, and Classification of On-Ice and Underwater Noise Sources Using Machine Learning

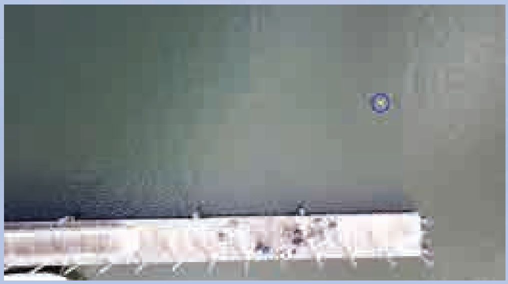
Professor:
Timothy C. Havens
Andrew Barnard

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

Michigan Technological University

Because there is less ice in the Arctic environment for longer time periods during the year, there is expected to be increased near-shore anthropogenic activity. This activity may come in the form of Arctic shipping through the Northwest Passage, natural resource exploration, tourism, and both foreign and domestic military activity. It is of interest to determine the location and type of these anthropogenic activities for situational awareness in the ocean battlespace. The challenge that we are investigating in this project is how to apply modern deep learning methods to acoustic vector sensors—sensors that simultaneously measure acoustic pressure and acceleration time-series data to localize, track, and classify anthropogenic sources. We will examine how deep learning can be used both on the raw time-series measurements, and also post-processed frequency-domain measurements.

The primary objective of the MTU NEEC project is to provide hands-on, militarily relevant educational opportunities for graduate and undergraduate students in under-ice acoustics and machine learning. The secondary objective of the project is to advance the understanding of multi-modal acoustic localization, tracking, and classification in ice-covered, shallow-water zones using machine learning methods. This will be done by conducting a suite of under-ice and on-ice acoustic experiments and analyzing the collected data with modern machine learning techniques to localize, track, and classify anthropogenic sources.



Bird's eye view of an experiment where a drone is tracking the position of an underwater ROV, while two underwater acoustic vector sensors are recording the ROV's acoustic signature.

Student running an experiment to localize an under-ice ROV using its acoustic signature in the middle of the Keweenaw Waterway at Great Lakes Research Center.

Students preparing an experiment where a drone is tracking the position of an underwater ROV.

NUWC Newport

University of Tennessee, Knoxville

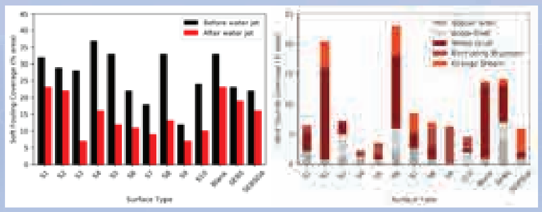
Fouling-Resistant Elastomeric Coatings based on Self-Organizing Heterogeneous Surfaces

Professor:
Gila Stein
Mike Kilbey

Students:
- Undergraduate: 1
- PhD: 2

The settlement and colonization of marine organisms on submerged surfaces can be inhibited with coatings that frustrate these processes. Fouling-resistant coatings are generally categorized as “biocide-release” or “non-biocide-release”, and each platform has distinct design considerations. Biocide-release coatings are designed to steadily release toxins (biocides) that degrade a growing biofilm, and they have been prevalent in the market for several decades. However, the biocides can also have deleterious effects on the surrounding marine life. In contrast, non-biocide-release coatings use chemical and physical interactions to resist marine fouling, which provides an “environmentally friendly” approach to protect surfaces.

The goal of this research program is to develop non-biocide-release elastomeric coatings that protect large-area surfaces from marine fouling. The approach is based on commodity elastomers that are functionalized with additives called macromolecular brushes. These unique additives were synthesized from chemistries with known anti-fouling and/or fouling-release properties. The team prepared six types of brush-functionalized elastomers as well as four blends based on either two or three types of brush-functionalized elastomers. Each formulation (S1-S10) was applied to large-area fiberglass panels and submerged in the ocean for over 100 days to evaluate its resistance to both soft and hard foulants. Sample preparation and data analysis were performed in accordance with ASTM D6990-20. These studies reveal significant differences in performance with respect to both total fouling coverage and the prevalence of different organisms. Notably, this first design iteration already yields promising formulations.



Left: Hard fouling coverage on brush-functionalized SEBS elastomers (S1-S10). Control samples were a bare fiberglass panel (“blank”), unfunctionalized elastomer (SEBS), and elastomer functionalized with 1-2 mol% dopamine (SEBSDA). Right: Soft fouling coverage for the same samples, before and after cleaning with a water jet (calibrated to reproduce 11 knots).

Will Ledford and Travis Laws working on purification of reagents for SAMB synthesis.

Student working with his NUWCNPT mentors, Drs. Wayne Tucker and Tom Ramotowski, during the summer 2021 internship. They are inspecting panels that were submerged at the start of the summer. (Still from NEEC promotional video, https://www.navsea.navy.mil/Home/Warfare-Centers/Partnerships/NEEC/.)

NUWC Newport

Performance of Elastomeric Coatings and Coated Structures Subjected to Long Term Seawater Submersion, UV Radiation, and Arctic Temperatures under Extreme Loading Conditions

Professor:
Arun Shukla

Students:
- **Undergraduate:** 4
- **PhD:** 1

University of Rhode Island

Marine structures are routinely coated with elastomers to enhance their survivability and reliability. These elastomeric coatings are corrosion and abrasion resistant, and they substantially mitigate the damage caused by shock, blasts, and impact loading on structures. These coated structures are exposed to aggressive marine environments (saline water and UV radiation) during service, which can deteriorate and alter the material properties of the elastomer and the strength of the interface over time. The use and deployment of these payloads, especially with composite materials, requires additional understanding of the adverse effects of long-term seawater immersion. The overall objective of this project is to under-stand the fundamental physics and to quantify how the structural integrity of a payload with elastomer coating is affected after a prolonged exposure to the aggressive conditions that marine environments can present.

The marine environmental conditions considered in this project are exposure to saline water, exposure to UV radiation, experimentation under arctic temperatures of interest to the Navy, high hydrostatic pressure, and external shock loadings such as UNDEX. The degradation due to prolonged exposure will be simulated by employing accelerated life methods conducted under high temperature, and experimentation will be carried out using appropriate facilities at the University of Rhode Island.

The project consists of five tasks, starting with the mechanical characterization of the elastomers of interest (polyurea and polyurethanes). The second task investigates the changes in the peel strength of metal/elastomer interfaces after long term exposure to saline water. The third task examines the dynamic underwater collapse of cylindrical shells coated with elastomer (polyurea), after they have been environmentally degraded (exposed to saline water and UV radiation). In the fourth task, the air blast behavior of coated carbon composite plates is studied. Coated plates will be exposed to UV radiation, saline water, and an alternation between UV radiation and saline water. The last task will develop corresponding computational models of the experiments (in stages 1, 2, 3, and 4) to support validated modeling practices for the reduction of expensive qualification testing.

Dr. Irine Chenwi, setting up high speed cameras for implosion experiments in the pressure vessel. This tank is a unique facility in the Dynamic Photo Mechanics Laboratory – URI, which simulates an open ocean environment. It is designed to withstand pressures up to 1000 psi and experiments in task 3 of this project are conducted in this facility.

Undergraduate student in the department of mechanical engineering, conducting experiments on the Split Hopkinson Pressure Bar (SHPB) setup in the Dynamic Photo Mechanics Laboratory, URI. The SHPB setup is used for material characterization under dynamic loading conditions.

NUWC Newport

Bioinspired Physical Deep Learning Paradigm for Sonar Sensing in Cluttered Environment

Professor:
Rolf Müller

Students:
- Undergraduate: 5
- PhD: 1

Virginia Polytechnic Institute and State University

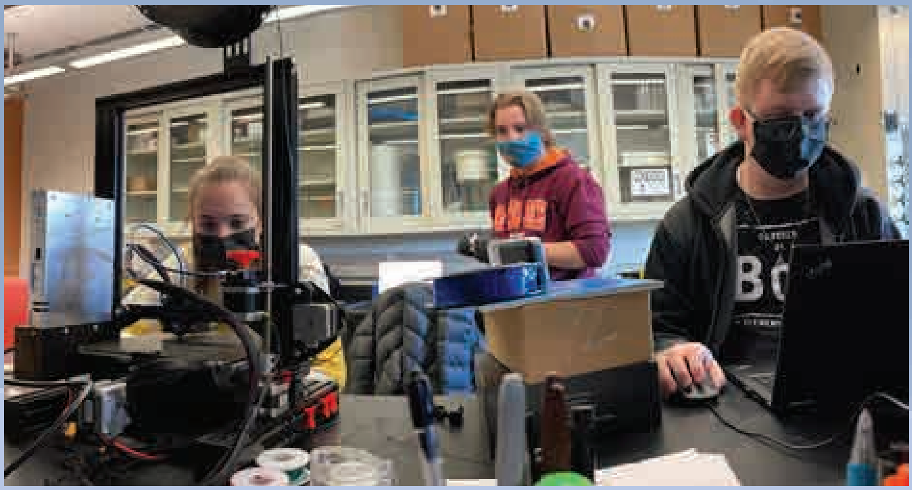
The goal of this project is to develop a soft-robotic sonar system with integrated deep learning that is capable of performing useful sonar-sensing tasks in cluttered environments such as natural foliage. This work is inspired by the biosonar sensing of certain bat species with particularly sophisticated biosonar systems such as horseshoe bats and Old World leaf-nosed bats.

On the soft-robotic side, the project aims at reproducing the complex static geometry and dynamics of the noseleaf (emitter) and pinnae (receivers) that is a prominent feature of the biosonar in the bat species that serve as a model here. A pneumatic actuation system with three degrees of freedom for non-rigid motions per pinna has been designed and is currently being readied for research use. The next generation of the system that is currently under development will utilize a tendon-based actuation system which we hope will increase the number of degrees of freedom and hence allow for a more accurate recreation of the variability in the biological motion profiles. At the same time, we aim to decrease the system weight and acoustic noise created by the sensing system to improve handling and the quality of the signals available for analysis.

In addition to developing the mechanical, electrical, and software aspects of this project, work is underway to implement machine learning algorithms on the biomimetic soft robot that will eventually integrate control of the peripheral dynamics and signal analysis. At present, approaches for analyzing "clutter echoes" for the purpose of identifying sonar landmarks and finding passageways in natural environments are under development. Pilot studies with the integrated system consisting of biomimetic periphery and deep learning have shown the abilities to find narrow gaps in foliage reliably, map an environment with precisions that are comparable to GPS, and determine the direction of a sound source using only a single receiver and a single acoustic frequency.

The ongoing research work translates directly to naval applications, especially in the context of autonomous underwater vehicles that need to navigate and accomplish their goals in cluttered, shallow- water environments. It could enable AUVs that are not only very capable in their sonar sensing but at the same time small and highly energy efficient.

Rendering of the CAD model for the shell and interior for the next-generation prototype of the biomimetic sonar head with soft-robotic, tension-driven actuation.



Student team working on a tension controlled biomimetic pinna actuation mechanism as their senior design capstone.

NSWC Panama City

Geomagnetic and Bathymetry Based Navigation System for an AUV

Professor:
Manhar Dhanak
Edgar An
Pierre Beaujean

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

Florida Atlantic University

An alternative approach to using GPS is geophysical navigation, involving utilization of environmental features for localization, using sonar, stereo cameras, or magnetic field maps. Here, we develop 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, are developed that primarily use INS plus a DVL to navigate to a destination, but make required corrections to the path through measurement of the local bathymetry and magnetic fields using onboard sensors, and matching them with available onboard maps of the bathymetry and geomagnetic field. Experiments are being carried out to obtain geomagnetic and bathymetric data in the vicinity of FAU. Simulations are 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 can be implemented on an available REMUS AUV and navigational experiments are actively being carried out to determine the performance of the vehicle's navigation in the field.

Student performs experiments on a REMUS 100 AUV.

Student looks at post-mission data from a REMUS AUV after field experiments.

NSWC Panama City

Understanding Cybersecurity Implications of Using and Protecting Unmanned Aerial Vehicles

Professor:
Mike Burmester
Daniel Schwartz

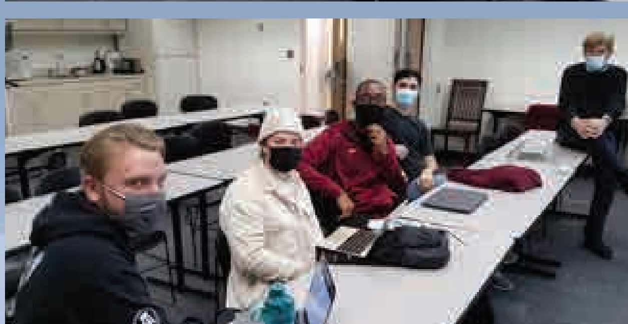
Students:
- Undergraduate: 3
- Master's: 1

Florida State University

There are increasing concerns that foreign manufactured unmanned aerial systems may leak sensitive data to their manufacturers, particularly since such systems are used for reconnaissance and surveillance of critical infrastructure, and more generally in applications that involve national security.

We investigate the challenges of securing and defending such systems, focusing on civilian Group 1 (small) drones (quadcopters) and propose a solution based on an architecture that complies with the policies and standards of the Committee on National Security Systems for the Cybersecurity of Unmanned National Systems CNSSP 28, in which software components are adapted/modified appropriately, and security policies/mechanisms are enforced. Protection builds on isolation, encapsulation, and the use of cryptographic tools.

We conclude by showing that a symmetric-key variant of Wyner's wire-tap channel can be used for offensive/defensive protection. This involves a number of friendly noisy drones acting as interferers to degrade signals and mitigate eavesdropping at the physical layer by exploiting properties of the wireless medium such as the inherent noise and the superposition property (interference), to secure communication (jam-based security).



Students and faculty meet to discuss research.

Students present their work to faculty during a research meeting.

NSWC Panama City

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

Professor:
Ananya Sen Gupta

Students:
- PhD: 1

University of Iowa

We develop a robust physics-cognizant mathematical framework to represent and differentiate different classes of acoustic echoes from proud, buried and semi-buried targets. More generally, we aim to detect and disambiguate potentially overlapped spectral features from diverse undersea scatterers using active sonar signaling for classification of underwater targets. We also propose to employ similar methods for underwater acoustic channel interpretation as part of naval communication systems to aid dynamic node placement of acoustic sensors. The bold departure in our proposed effort from the current state-of-the-art lies in employing geometric signal processing rather than algebraic and/or statistical techniques (e.g. subspace separation methods to differentiate classes of echoes). The key intuition is to represent non-linear overlap between spectral features using geometric braid and knot theory, which is mathematically well-suited to encode/decode overlapped "shapes" that may undergo smooth deformations over time, space, frequency, and other parameters. Our innovations lie in integration of acoustic scattering physics with sonar spectral analysis, and therefore, are naturally suited to interface between domain knowledge and emergent techniques in machine learning. We achieve this by harnessing Gabor wavelets that match models of elastic wave orbits with manifold signal processing techniques that embed braid and knot encoding onto sonar signaling schemes. This allows human expert interpretation of learned features which can provide critical and nuanced understanding of why different learning techniques select different elements of spectral morphology. In particular, our methods are aimed at (i) detecting features that morph smoothly across different scattering angles and ranges, and (ii) unraveling overlapped features that exhibit distinct spectral topology and therefore, potentially represent different classes of acoustic echoes. Results of this project will also lead to dynamic interpretation of acoustic scattering signatures which will potentially aid adaptive node placement.

Student and faculty meet during a Zoom meeting.

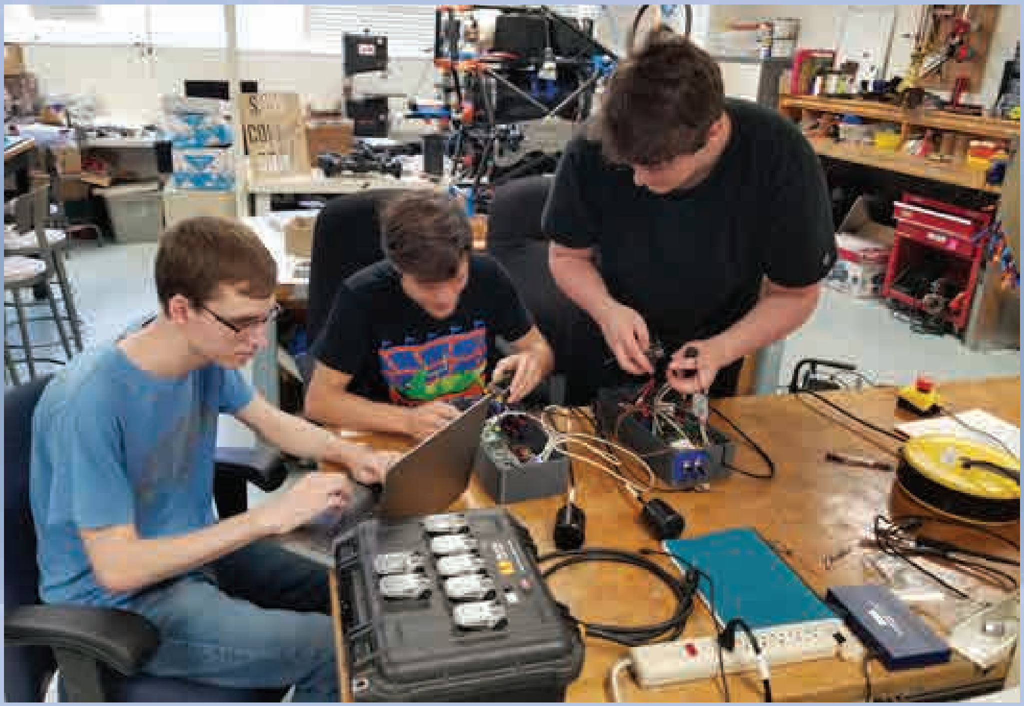
Collaborative Maritime Systems

Professor:
Warren Dixon
Eric Schwartz

Students:
- **Undergraduate:** 15
- **PhD:** 3

University of Florida

The University of Florida (UF) efforts are supported by two collaborative laboratories: the Nonlinear Control and Robotics Lab (NCR, http://ncr.mae.ufl.edu/index.php?id=ncr) and the Machine Intelligence Lab (MIL, www.mil.ufl.edu). The goal of the UF efforts is to investigate methods for collaborating autonomous underwater and surface vehicles (AUV and ASVs). The ASV sends navigation information to a collaborating relay agent AUV through an acoustic modem (or alternatively, the relay agent can surface to get navigational information without an ASV). The relay agent AUV then visits AUVs agents of an exploration network (i.e., AUVs that are tasked with a survey task). The relay AUV provides navigational updates to the exploring AUVs by shuttling back and forth between an area where navigational feedback is available and the exploring agents (where feedback is not available). This goal requires AUV navigation and control efforts, efforts in communicating through the acoustic modem, and timing conditions that determine when each explorer AUV needs navigational feedback service from the relay AUV.



Students working on acoustic modem integration.

NSWC Panama City

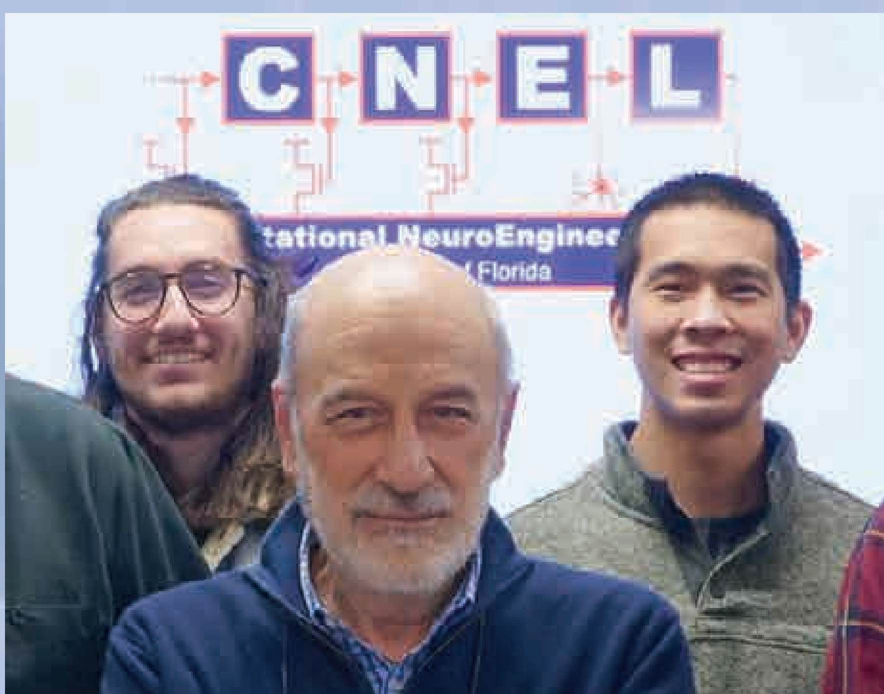
Understanding Deep Learning Architectures with Information Theory

Professor:
Jose C. Principe

Students:
- PhD: 3

University of Florida

We seek to improve the training, hyper parameter selection and generalization ability of learning machines using a combination of machine learning and information theoretic concepts. Our ultimate goal is to improve the available quantification tools to give more confidence to designers and users alike and improve the transparency of this class of algorithms. Quantifying the generalization ability of supervised learning machines is a difficult problem that is associated with their capacity. We propose a different framework by blending machine learning and information theory. We have recently utilized an information theoretic learning (ITL) framework (proposed by the PI) to train a stacked autoencoder (SAE) using an ITL constraint (ITL-AE). Second, we have used ITL to demonstrate that this capacity is shared by two flows of information, one from the input and one from the supervising target. Third, we have applied ITL to explain the learning dynamics of SAEs and the best architecture design choices for the residual network (ResNet). We believe that ITL can provide the needed mathematical underpinning to quantify information transfer in deep architectures and seek optimal topologies that generalize the most for unseen data belonging to the same distribution of the training set. The Navy is increasingly more dependent from information systems using Deep Learning, so providing more explainability to the computation and more ways to optimize the training is of great importance.



Students with Prof. Principe in the CNEL lab.

NSWC Panama City

Robust and Reversible Deep Networks

Professor:
Alina Zare

Students:
- Undergraduate: 1
- PhD: 1

University of Florida

Deep learning architectures are being used more and more frequently including in synthetic aperture sonar (SAS) analysis. However, deep learning architectures have been repeatedly shown to be brittle in performance and lack stability. In particular, small changes (imperceptible to the human eye) can result in large changes in output. Furthermore, deep learning architectures are generally unable to effectively exhibit competency-awareness. In other words, deep learning methods always provide an output regardless of how unlikely or surprising the input. These architectures are generally unable to provide the "I do not know" output when provided an input sample that is unlike the training data set. Finally, decisions and outputs produced by deep learning systems are difficult to interpret and explain. Explainability allows for ensuring reliability. These three characteristics (competency awareness, outlier rejection and explainability) are critical components in producing a trustworthy system. The overall goal of this research is to develop a suite of methods to improve the trustworthiness of deep learning architectures for synthetic aperture sonar analysis.

Students meeting to discuss experiment results.

NSWC Panama City

Algorithm Development for Ultrasonic Sensing System for Target Detection

Professor:

Jason Mitchell
Brett Byram
Jack Noble

Students:

- **Undergraduate:** 5
- **PhD:** 3

Vanderbilt University

VANDERBILT UNIVERSITY

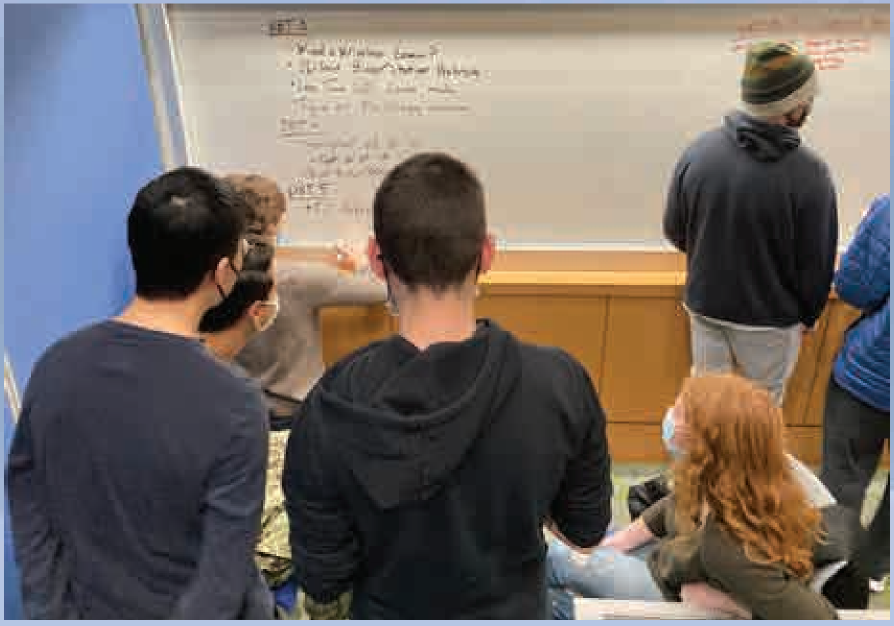
Low frequency broadband sonar has been used for decades in towed arrays and more recently in Autonomous Underwater Vehicles to find targets. These systems work up to the low frequency range and can image over relatively long distances, but image resolution is limited. Higher frequency diver operated sonar systems have also been developed. These are intended to image several meters, allow 2D tomographic visualization of their immediate surroundings, and have significantly higher resolution.

Our lab is currently developing an ultra-high frequency, 8-10 MHz, sonar system for underwater visualization, intended to image out to 1 meter with sub-millimetric resolution in order to create 3D projection images of objects.

The overarching goal of the current proposal is development of software needed to automatically and efficiently enhance and analyze images obtained by our system to produce high resolution imagery. We will leverage our expertise in acoustics, signal processing, image formation, image analysis, and machine learning to guide undergraduate engineering student research towards this goal. Specifically, we will use machine learning techniques to improve image acquisition and reconstruction efficiency. Software will be developed to analyze raw data being collected by the sensor to identify objects of interest. Depth maps can then be more efficiently reconstructed by limiting the computation to identified regions of interest.

Year 2 has focused on hardware development of scanning hardware.

Students test an underwater winch system for an undergraduate capstone involving unmanned underwater vehicle docking supported by the program.



Students discuss system design during an undergraduate capstone project supported by the NEEC program.

Naval Education Ecosystem Design for Battery Pack Agnostic Intelligent Battery Management Systems

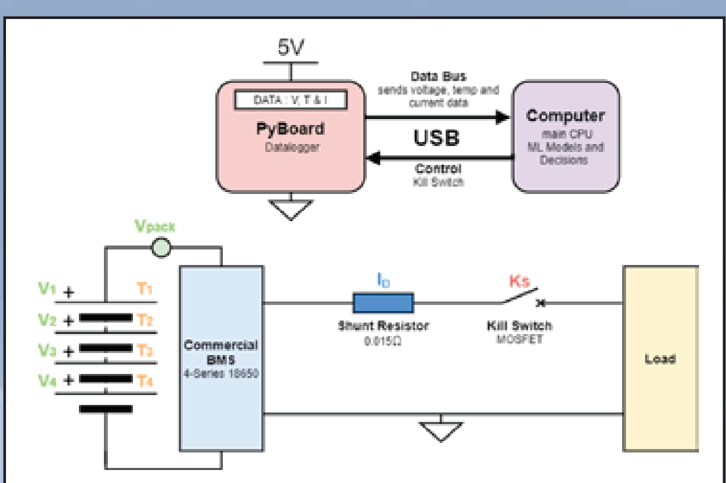
Professor:
Vikas Tomar (PI)
Edwin Garcia
Dr. Tom Ada

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

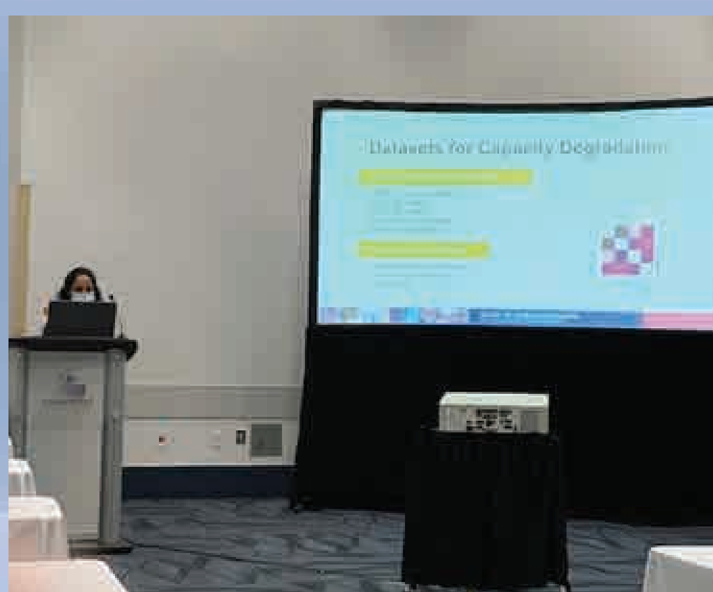
Purdue University-West Lafayette

The proposed work will deliver an intelligent autonomous battery management system (SBMS) prototype that is agnostic to the type of vendor supplied lithium-ion (Li-ion) battery pack. The first 3 years of the proposed work will focus on delivering the solutions with emphasis on first three bullets above in case of commercial 12VDC Li-ion battery packs. The overlay SBMS will be applied to commercial 12VDC Li-ion batteries from 3 different vendors with proprietary BMS systems, and the algorithms and proof of concept of an autonomous management system overlaid would be proven at scale. Once scalability and usability is established with prototypes that are demonstrated for, the next phase will focus on NAVY specific energy storage system requirements such as PP-8498 portable charger or much higher capacity energy storage systems approaching 1000 VDC. Extreme environment abuse, projectile impact, cybersecurity protocols, and NAVSEA 9310 or similar operational standards will be applied for and ensured in the final phase. The SBMS has been designed and is now focused on testing on UAVs. The SBMS has the following features:

1. It is able to be mounted on any vendor supplied battery back with its own battery management system;
2. It is modular in nature and can be scaled to larger number of packs or increase in energy delivery capacity of packs;
3. It allows users to be able to check state of health of a battery pack in real time and it incorporates data modules that have embedded machine learning protocols that learn from the battery pack operation as a function of usage to help in optimal management of battery packs; and
4. The SBMS allows interfacing with other electronic components for ensuring implementation of cybersecurity protocols.



Layout of the agnostic Battery Management System.



A supported student presenting work at TMS annual meeting in Anaheim, CA. Feb 2022.

NSWC Philadelphia

Polymer Nanocomposites with Enhanced Dielectric Strength and Reduced Thermal Contraction for Superconductor Cables

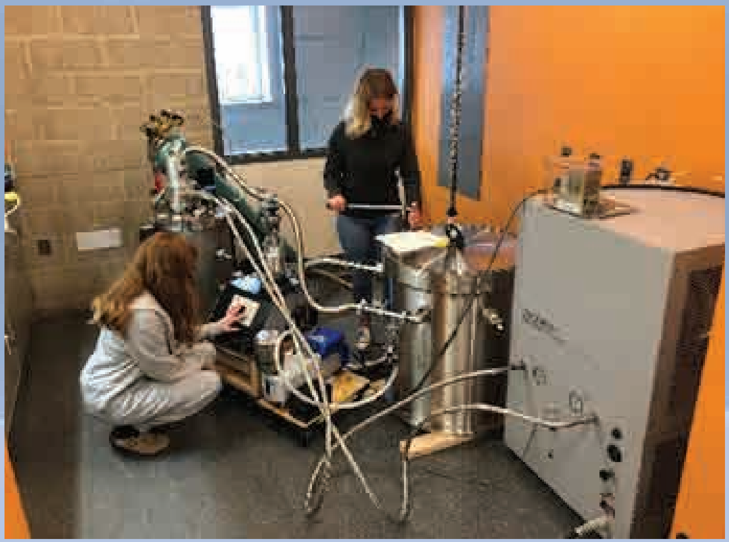
Professor:
Wei Xue
Robert R. Krchnavek

Students:
- **Undergraduate:** 52
- **Master's:** 5

Rowan University

Using high-temperature superconducting (HTS) systems to revolutionize the efficiency of power transmission can solve major energy conversion and distribution challenges for modern energy systems and the overall energy infrastructure. However, realizing the benefits of HTS systems comes with the need to address a variety of material challenges associated with existing HTS technologies, specifically with the fragility of thin-film dielectric coatings in cryogenic operating environments.

The research team at Rowan University has been investigating advanced dielectric composites that are better suited for these HTS systems. Different types of polymer-nanoparticle composites have been designed, fabricated, and characterized, with the intent to improve the thermomechanical performance of dielectrics while maintaining their high breakdown strength. Accordingly, a variety of novel and fully customized experimental test systems have been designed, manufactured, and implemented in order to effectively characterize the material behaviors in the cryogenic environment. The new dielectrics will provide critical benefits such as wider temperature windows, additional design flexibility, higher current density, and large power capacity for applied superconductor systems. They will be particularly useful in gas helium cooled HTS systems on Navy ships. This project has involved strong student participation at both graduate and undergraduate levels, providing substantial research work for 5 graduate students and more than 50 undergraduate students.



Undergraduate students working on the custom-made cryogenic testing chamber.

Students collecting dielectric data on thin film samples.

NSWC Philadelphia

Unifying and Securing Naval SCADA Networks through Scalable SDN

Professor:
Temple: Liang Du
Penn State: Yan Li

Students:
- **Undergraduate:** 4
- **Master's:** 5

Temple University & 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 emulator (e.g., MiniNet and MaxiNet), SDN framework (e.g., Ryu), and packet analyzer (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 in 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.

Temple students assemble a server rack and wire up multiple programmable logic controllers to form a demo naval vessel supervisory control and data acquisition (SCADA) network.

Temple students work on the software and programming part to initiate efforts on how to define networking from software's point of view.

NSWC Port Hueneme

Robust Inside-Out Simultaneous Localization and Mapping for Environment Monitoring and Equipment Maintenance

Professor:
Tobias Höllerer

Students:
- **Undergraduate:** 13
- **Master's:** 1
- **PhD:** 4

University of California, Santa Barbara

Effective surface ship maintenance is a significant challenge for the U.S. Navy's large fleet, which should be maximally operational with minimal time spent in maintenance. There is thus a huge incentive to reduce maintenance time by employing better procedures and state-of-the-art technology to increase throughput and success rates in maintenance operations.

This effort contributes basic research towards new capabilities that employ computer vision and machine learning technologies to track users with mobile augmented reality (AR) devices robustly and reliably in indoor (water or land-based deployment and training spaces) or outdoor environments, using only local (hand-held device or body-worn) sensors, and assuming no prior preparation of the environment that AR assistance will occur in. Our scene modeling, tracking, and registration approach constructs and maintains a hybrid model of a large tracking environment, and utilizes machine learning for geometric and semantic modeling of key environment objects. The team has made significant progress on three fronts: 1) Scene reconstruction from SfM/SLAM and AR camera feeds via novel deep learning architectures; 2) interior scene understanding via machine learning; and 3) UI demonstration and evaluation for task switching during AR maintenance (using the HoloLens-2)

We have involved and mentored undergraduate researchers and high-school research interns right from the beginning of this effort, and these activities have resulted in several conference publications with the high-school mentees as lead authors, including a full paper at CVPR 2021!

Participants navigating an augmented outdoor environment using HoloLens-2.

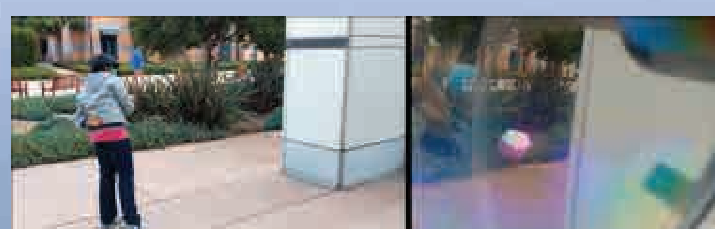
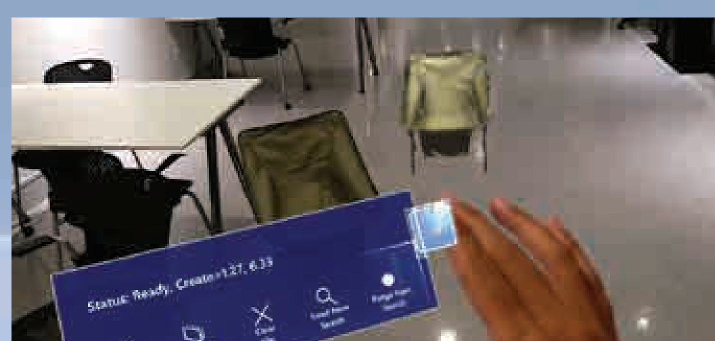


Image capture using the HoloLens-2.



AR experience of digital twin objects using our computer vision methodologies. Image captured via HoloLens-2's MR Capture.

COVIA: Computer Vision based Intelligent Assistant for Mistake Proofing of Complex Maintenance Tasks on Navy Ships

Professor:
Rahul Rai

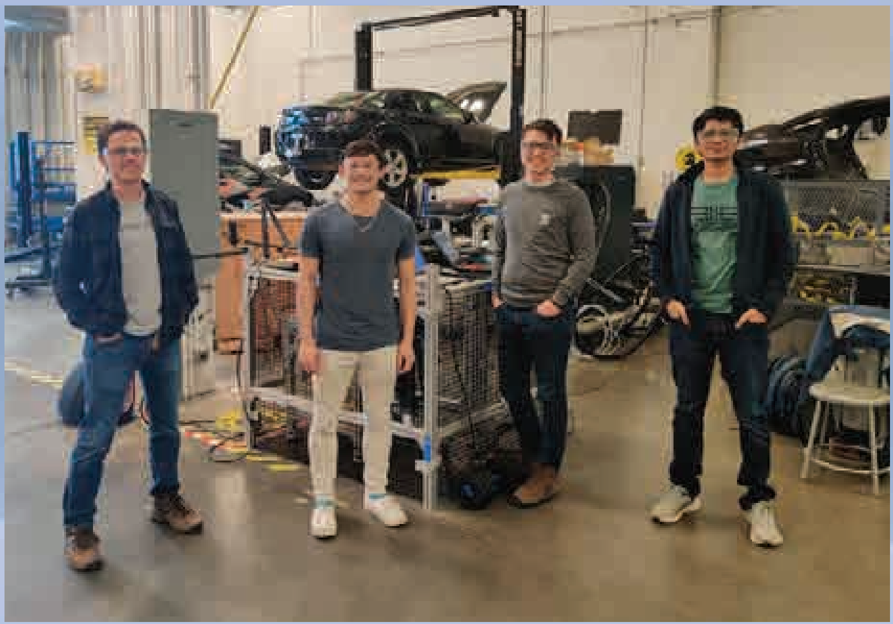
Students:
- **Master's:** 1
- **PhD:** 2

Clemson University International Center for Automotive Research & Clemson University

The maintenance service is an important task for the Navy. The Navy is responsible for managing maintenance on all its ships throughout each ship's service life. The purpose of this Naval Engineering Education Consortium (NEEC) project is to investigate advanced deep learning based computer vision methods and algorithms to enable next-generation Handheld Augmented Reality (HAR) based complex maintenance tasks. The project is focused on enabling a human-AI communication channel to improve diagnostics and prognostic health monitoring; additionally, the project has developed a pipeline for reconfiguration of systems undergoing failures to improve machine maintenance.

Our maintenance solution, which is currently being developed as an Android app and applied to a 3D printer for proof of concept, has three main components: an object tracking algorithm, a procedure creation process, and a procedure reconfiguration method. The object tracking algorithm uses deep learning, specifically Generative Adversarial Networks (GANs), to aid the user while performing maintenance by identifying and tracking relevant parts of the system. The procedure creation process draws from areas of ontology and disassembly sequence planning in order to automatically create procedures for the user based on the specified target component and optimization objective. Finally, a unique component of this solution is the inclusion of the ability to reconfigure a procedure while it is being performed. The combination of these components makes for a unique, impactful, and innovative solution for performing maintenance.

Graduate students working on the COVIA project collecting failure data from a bearing test rig at the Clemson University International Center of Automotive Research.



Ph.D. students at the Clemson University International Center of Automotive Research for collecting data for the COVIA project.

NSWC Port Hueneme

Augmented Reality-Assisted Maintenance Operations of Underway Replenishment System (URS)

Professor:
Aaron Elkins,
Bongsik Shin

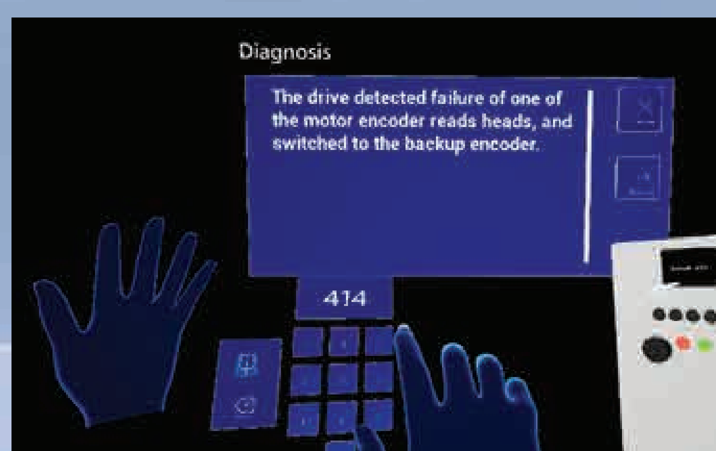
Students:
- **Undergraduate:** 2
- **Master's:** 1

San Diego State University

SAN DIEGO STATE UNIVERSITY

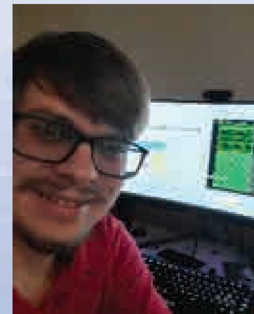
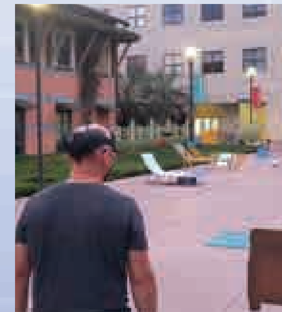
Our team from the AI Laboratory is currently working on developing applications that utilize augmented reality (AR) for the Naval Maintenance, Repair, and Overhaul (MRO) workforce. For this, we are designing and developing a prototype to assist with maintenance and emergency operations related to E-STREAM, an underway replenishment system (URS). The traditional MRO operation for the URS has not been effective as the workforce relied much on the manual process (e.g., maintenance logging, manual search of warning messages) in understanding the system functions and troubleshooting the problem source of system alerts. On deployment, the AR system will assist crews in troubleshooting and conducting MRO operations of E-STREAM by cutting the manual process and by streamlining the retrieval of data and knowledgebase. As another important function, we anticipated that the AR system can be used to facilitate the training of MRO tasks among sailors.

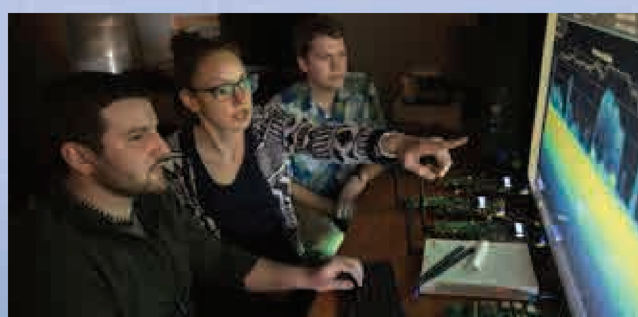
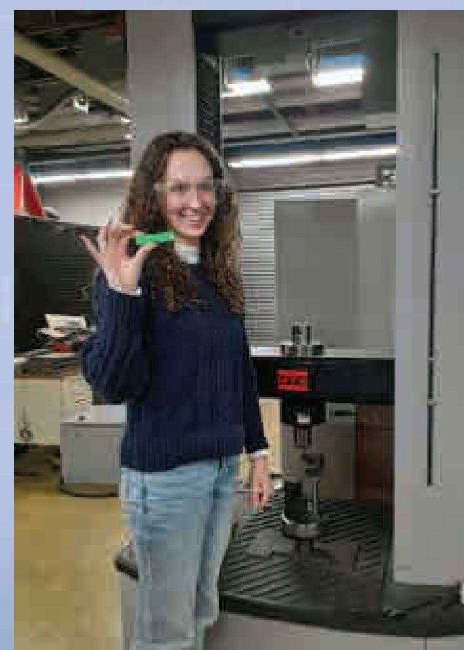
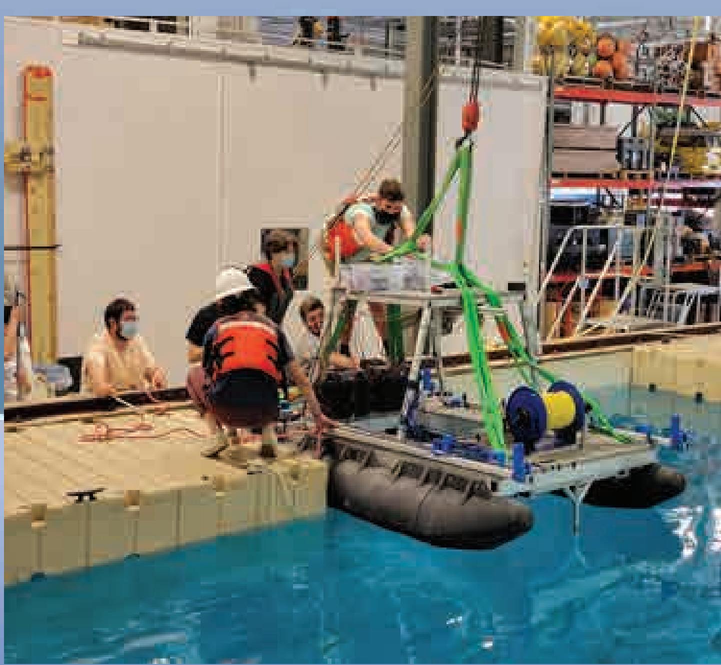
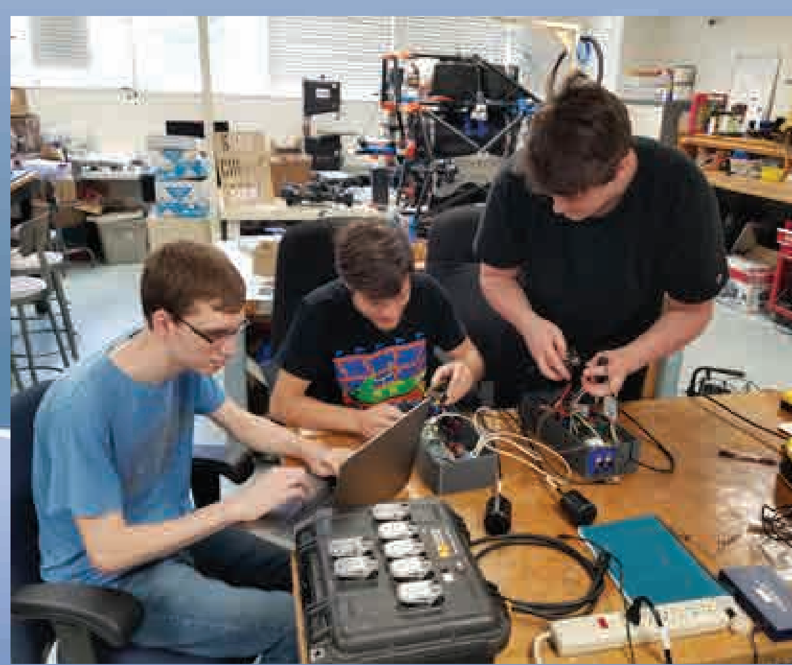
Faculty and students engaged in weekly research meeting.



Right- and Left-handed user Hand Menus for inputting error codes while using a Hololens 2 device.



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