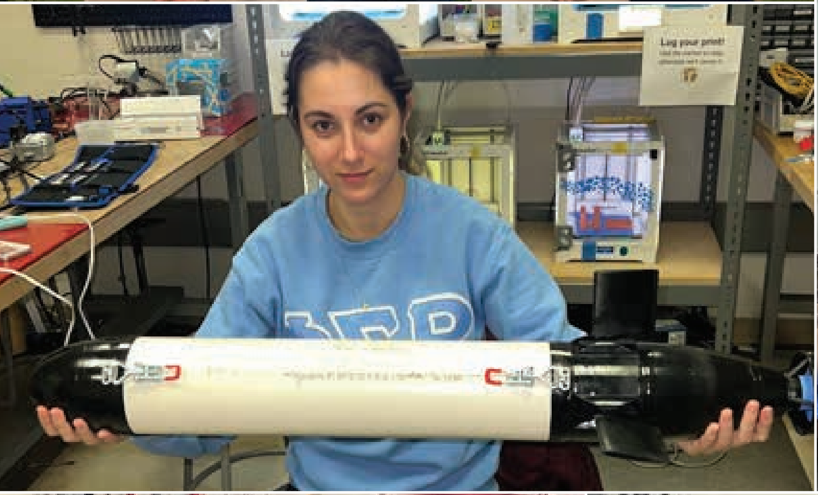
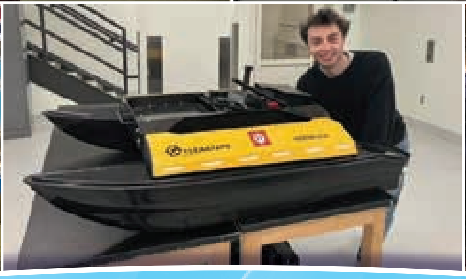
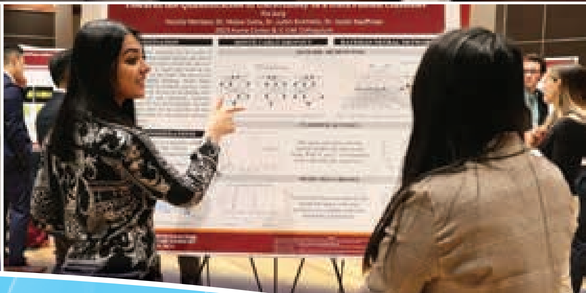
NAVAL ENGINEERING EDUCATION CONSORTIUM PROCEEDINGS 2023

2023 NEEC
Naval Engineering Education Consortium







NEEC

Naval Engineering Education Consortium

NAVAL ENGINEERING EDUCATION CONSORTIUM PROCEEDINGS

2023

About NEEC

For more than a decade, the Naval Engineering Education Consortium (NEEC) has brought students, teachers, Navy scientists and engineers together to explore current and future technical challenges through project-based research for the purpose of attracting and accelerating the development of the next generation of naval engineering talent. Amid intensifying global technological competition, it is now more than ever crucial that we strengthen America's science and engineering workforce and encourage closer collaboration with academic partners to create an enduring advantage for the U.S. Navy and the nation.

NEEC was expressly established to accomplish these goals. Directed by the Naval Sea Systems Command Warfare Centers and implemented by the Warfare Centers' ten Divisions across the country, NEEC funds research and development in an academic environment and offers students who may be interested in pursuing civilian science and engineering careers with the Navy the opportunity to investigate real Navy challenges while working hand-in-hand with university faculty and Warfare Center mentors. Colleges and universities are invited to submit proposals for technical naval topics of interest and, if selected, receive grants for one year with options for second and third years. Each university or college chosen works with one specific Warfare Center Division, with its own NEEC director and mentors, on a wide range of topics that include natural language processing, hypersonic weapon advancement, novel energetic materials, zero-trust techniques, autonomous vehicles; and advance additive manufacturing. Our student participants are given a mandate to: Work hard and learn as much as possible! Ask the hard questions! Challenge the status quo!"

Over 400 aspiring scientific and engineering students enthusiastically took up this charge, and their successes are reflected in this year's NEEC Proceedings. Example projects include the development of bio-inspired autonomous vehicles used for detection and underwater infrastructure inspection; focusing on how the design of naval combatants will change to expand to icy waters (or operating in a broken ice field); understanding hypersonic flows around vehicles; challenges on performance and power of containerized virtual machines in a cloud setup; the use of liquid fuels on high-speed aircraft; and developing a more proactive obsolescence management approach, to name just a few.

Also evident on the pages of the Proceedings are the energy and commitment of their professors, our Warfare Centers scientists and engineers, mentors, NEEC directors, and a whole host of dedicated personnel who work so hard to bring each and every project to fruition. We are grateful to them all for their participation as part of the best talent assembled from our workforce and our government, industry, and academic partners to address the significant challenges facing the Navy and the nation.

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

Contents

About the Warfare Centers at the Naval Sea Systems Command (NAVSEA) 1

The Consortium 1

NEEC Directors 1

NSWC Carderock 2
- Boston University 2
- Florida Atlantic University 3
- University of Michigan 4
- University of Michigan 5
- Missouri University of Science and Technology 6

NSWC Corona 7
- University of California, Riverside 7

NSWC Crane 8
- Indiana University Bloomington 8
- Indiana University Bloomington 9
- North Carolina State University 10
- University of Notre Dame 11
- Purdue University 12

NSWC Dahlgren 13
- University of Puerto Rico Mayaguez 13
- University of Texas at Arlington 14
- University of Texas at Arlington 15
- Virginia Polytechnic Institute and State University 16
- Virginia Polytechnic Institute and State University 17
- University of Virginia 18
- Virginia State University 19

NSWC Indian Head 20
- Arizona State University 20
- University of Cincinnati 21
- Colorado School of Mines 22

Contents

NUWC Keyport 23
Embry-Riddle Aeronautical University 23
South Dakota School of Mines and Technology 24
University of Maryland 25
University of New Hampshire 26
University of Tennessee, Knoxville and Duquesne University 27
University of Washington 28
University of Washington 29
University of Washington 30
Washington State University 31

NUWC Newport 32
Baylor University 32
Howard University 33
University of Massachusetts Dartmouth 34
Virginia Polytechnic Institute and State University 35
Worcester Polytechnic Institute 36
Washington State University 37

NSWC Panama City 38
Florida Atlantic University 38
University of Florida 39
University of Florida 40
University of Iowa 41
Vanderbilt University 42
Virginia Polytechnic Institute and State University 43

NSWC Philadelphia 44
Purdue University Northwest 44
Temple University and The Pennsylvania State University 45
University of Tennessee, Knoxville 46

NSWC Port Hueneme 47
University of California, Santa Barbara 47
University of California, Santa Barbara 48

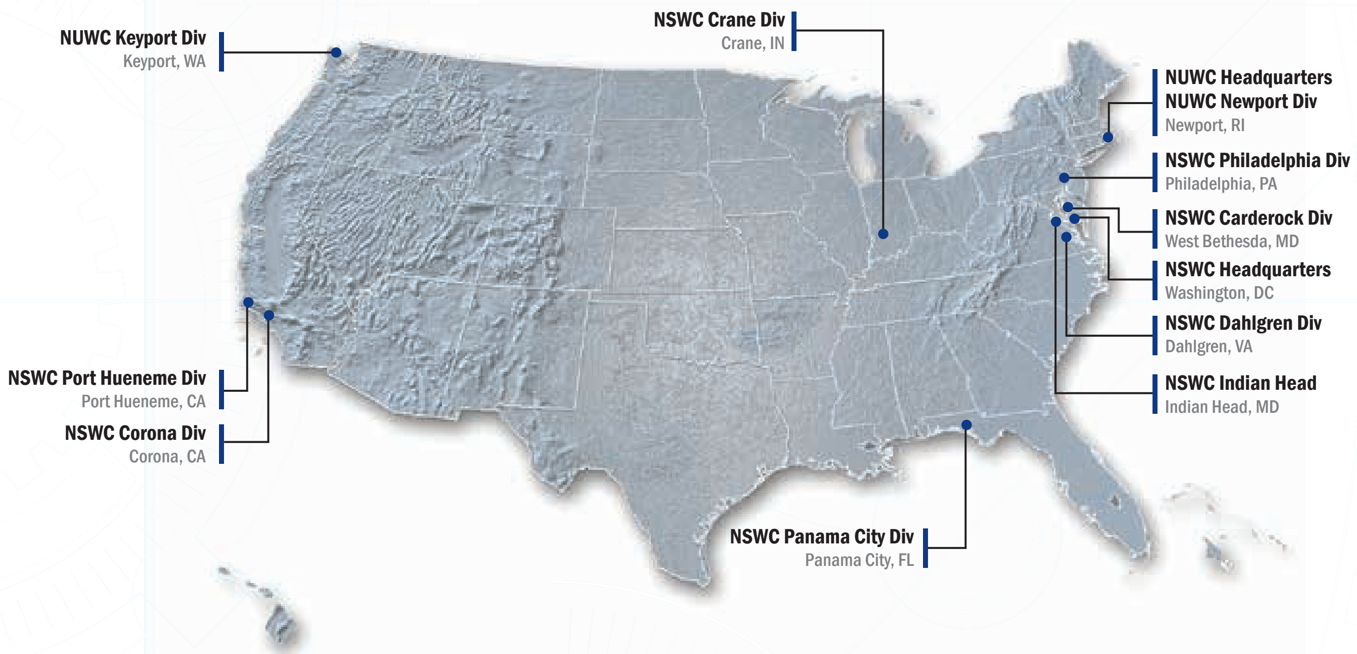

NAVSEA
WARFARE CENTERS
FLEET
UNDERSEA
SUPERIORITY
TODAY &
TOMORROW

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:
Sally Sutherland-Pietrzak

Naval Surface Warfare Center Division, Carderock:
Charlotte George and John Barkyoumb

Naval Surface Warfare Center Division, Corona:
Karon A. Myles

Naval Surface Warfare Center Division, Crane:
Bryan D. Woosley

Naval Surface Warfare Center Division, Dahlgren:
Patric Cantwell

Naval Surface Warfare Center Division, Indian Head:
Trevor Hedman

Naval Undersea Warfare Center Division, Keyport:
Thai B. Tran

Naval Undersea Warfare Center Division, Newport:
Elizabeth A. Magliula

Naval Surface Warfare Center Division, Panama City:
Matthew J. Bays

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

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

Imaging the Dynamics of Complex Connections

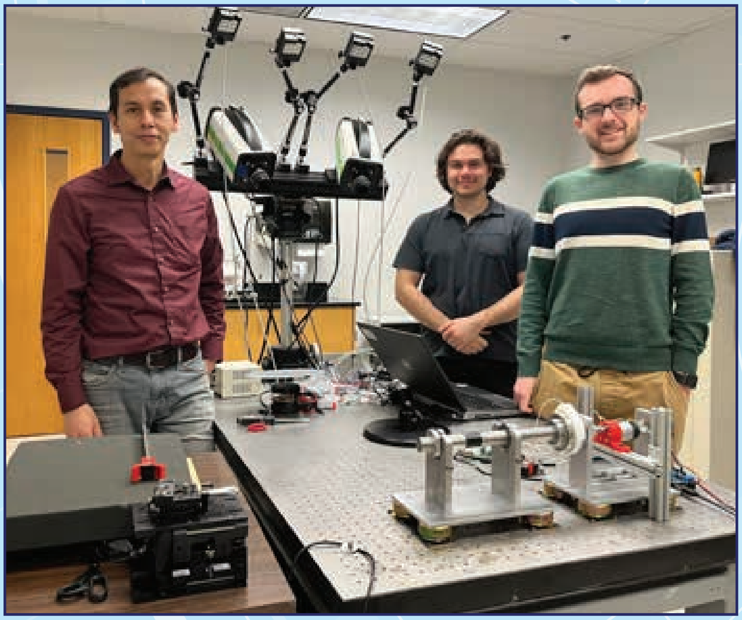
Professor:
James McDaniel

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

Boston University

Most structures of interest to the Navy contain connections, such as bolted assemblies, that defy modeling due to complex physical mechanisms that can only be experimentally measured. This research addresses this modeling challenge with a combination of experiment and analysis, opening the door for realistic simulations that support rapid design and prototyping. This research uses a novel experimental method for measuring the dynamic behavior of friction interfaces with complex geometries and loadings. The method employs two high-resolution and high-speed video cameras with digital image correlation to measure the three-dimensional motions of thousands of particles on vibrating surfaces surrounding the friction interface. Vibration of the friction interface is controlled by generating flexural, longitudinal, and torsional waves in beams connected to the interface.

Analysis of the experimental data results in a scattering matrix that relates incident waves to reflected and transmitted waves. The scattering matrix is then analytically related to a mechanical impedance matrix of the connection. The impedance matrix is directly imported into a finite element analysis of a system consisting of many such connections. Experiments vary critical parameters such as static stresses, contact stresses, and temperatures. This approach overcomes challenges faced by traditional approaches, which attempt to characterize interfaces in situ with a relatively large number of uncertain parameters and a relatively small number of vibration sensors. Ultimately, this research creates benchmarked and automated processes for using digital image correlation to compute the impedance matrix of any complex connection. This research brings substantially greater accuracies to the finite element analyses that are integral to rapid design and prototyping. This research transitions the new knowledge to inform the design of complex connections.



Project participants in the Sound and Vibration Laboratory, standing in front of the Vibration Imaging System used for this project and standing behind a rotational system being studied in this project. Professor Gutierrez-Wing (left) with students.

NEEC-sponsored student event at Boston University on February 15, 2023, titled "Engineering Freedom's Defenses / True Stories from Inspiring Engineers." This event was intended to inspire engineering students at Boston University to pursue careers at Carderock. A presentation was given by Eric Miller and Michael Kvartunas from Carderock. Boston University Professor Greg McDaniel gave a brief presentation on the NEEC project, highlighting collaboration between Carderock and Boston University.

NSWC Carderock

Senior Design Project in Support of Naval Applications

Professor: Pierre-Philippe Beaujean

Students:
- Undergraduate: 22

Florida Atlantic University

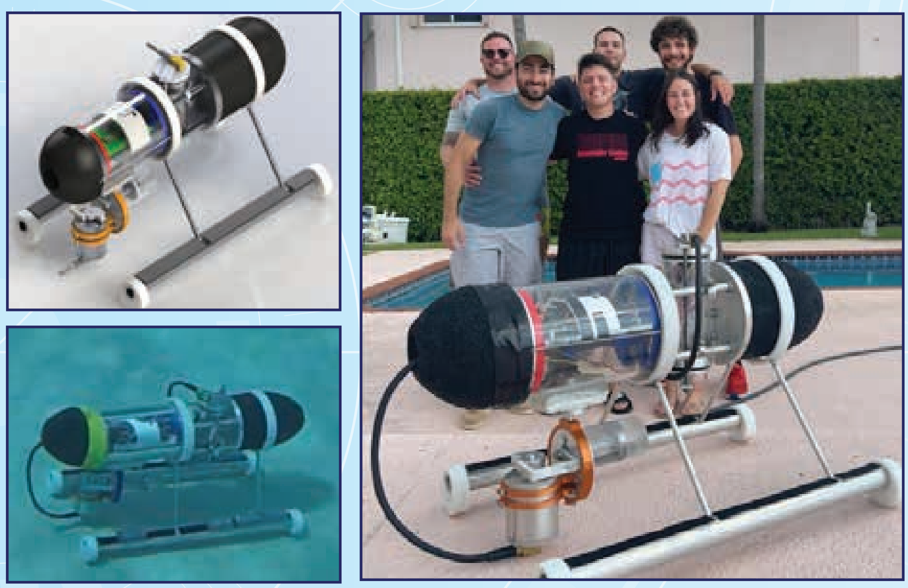
Students in the Florida Atlantic University (FAU) Ocean Engineering (OE) program are working to develop autonomous systems of naval relevance in the course of a two-semester capstone senior design project that involves designing, building, testing, and demonstrating complete systems. In addition to the development of an unmanned marine platform, students must provide design presentations to colleagues and stakeholders that address 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 autonomous systems and work in teams of 5 to 7 undergraduate students that are supported by faculty and technical staff. Projects sponsored by the NEEC program include:

- A Bio-Inspired Autonomous Underwater Vehicle to detect, track, and follow a surface moving object.
- A Bio-Inspired Self-Burying Autonomous Underwater Vehicle capable of landing on a sandy seafloor, partially burying itself in the seafloor, and releasing itself from the seafloor to continue its mission.

These projects aim to engage students with hands-on experience and promote both student interest and understanding of marine platforms, autonomy science, and naval technology. In the two projects cited, the Critical Design Review took place in December 2021, followed by fabrication until mid-March 2022, and demonstration in April 2022. These groups completed a series of successful pool tests and field tests. Figures 1 and 2 show the design, fabrication, testing, and team of each prototype.

Design and fabrication of the Bio-Inspired Self-Burying Autonomous Underwater Vehicle.

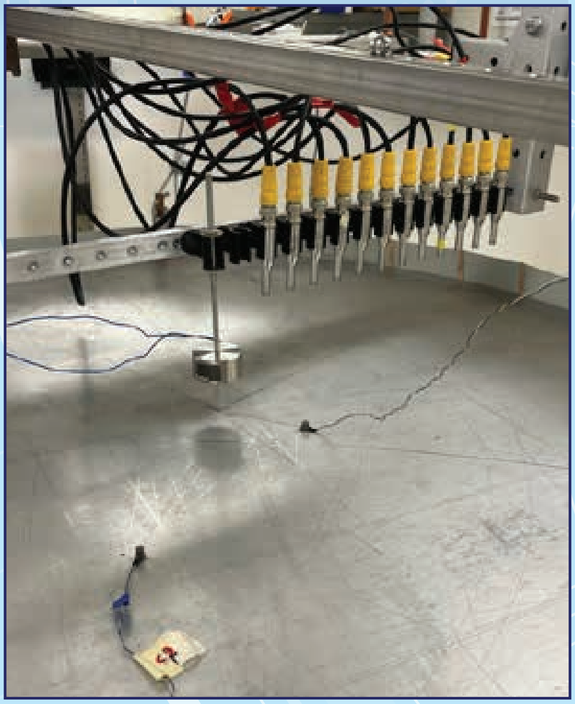


Design, testing, and team photo of the Bio-Inspired Autonomous Underwater Vehicle to Detect, Track and Follow a Surface Moving Object.

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

Professor:
David R. Dowling

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



Experimental setup for using radiated sound recordings to determine the location of an impact on flat plate. The plate surface fills the lower two-thirds of the picture. The recording array is 3 inches above the plate. The electromagnet used to hold and then drop a steel ball bearing is to the left of the microphone array.

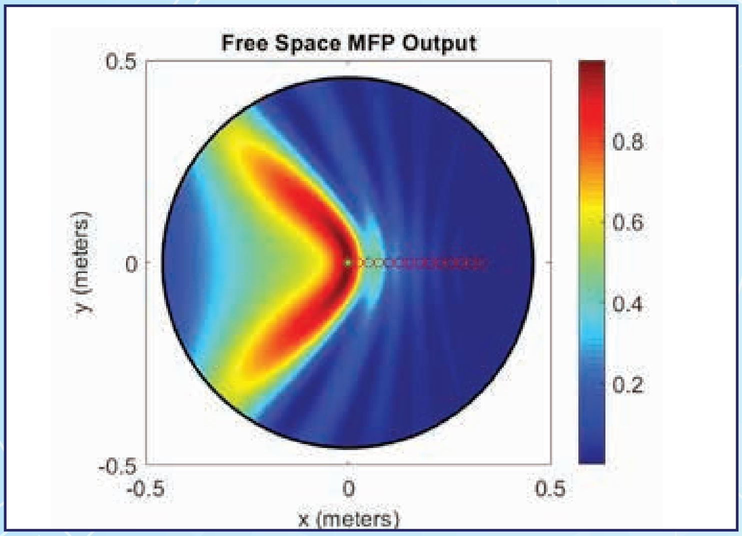
University of Michigan

Acoustic signature reduction and improved means for determining remote sound and vibration source characteristics are enduring priorities for the US Navy. Both of these priorities motivate research into new and better ways to analyze and process array-recorded acoustic and vibration time series collected in test facilities, on test ranges, and on Navy assets. This research and development program seeks to determine the utility of new array signal processing techniques for use in noisy and reverberant environments based on measurements collected from Navy-relevant objects and structures, while emphasizing the training of undergraduate and graduate students.

This project has three tasks that both emphasize experimental work and measured-signal analysis. (1) Design and conduct axisymmetric transient-impact simulations and experiments that include measurements of air- and water-borne sound radiated from a structure that is fluid-loaded by water on one side to determine the characteristics of the impact and the structure. The intent here is to find ways to remotely characterize impulsive and long-duration noise sources and to determine how fluid loading influences such characterization. (2) Develop and test hydroacoustic measurement techniques for surface pressure fluctuations caused by wall-bounded turbulent flows. The intent here is to develop better means for measuring a primary source of structural excitation. (3) Localize vibration sources on or within a cylindrical metal structure using measured time series from an array of accelerometers. The intent here is to develop and test data-driven machine-learning techniques for localizing and characterizing vibration sources that might be readily deployed on Navy assets.

Recent results for task (1) indicate that it may be possible to locate unknown impact locations based on radiated sound alone. Recent experimental results for task (2) have shown that mounting a surface pressure transducer below a pinhole may be a viable way to improve the resolution of surface pressure fluctuation measurements. Recent efforts on task (3) involve finding and validating a repeatable means for point-source excitation of the cylindrical structure.

These tasks are important for the US Navy as it seeks to monitor the acoustic source levels of its assets, the structural health of its assets, and the operation and condition of the machinery within its assets.



Simulated array signal processing results for localizing an impact on a flat plate based on radiated sound recordings. The color field coincides with the surface of the plate. The impact location is at (0,0). The microphone locations are marked by red circles. The acoustically-determined region of high likelihood is red to dark red.

NSWC Carderock

Design and Evaluation of Naval Vessels for Arctic Operations

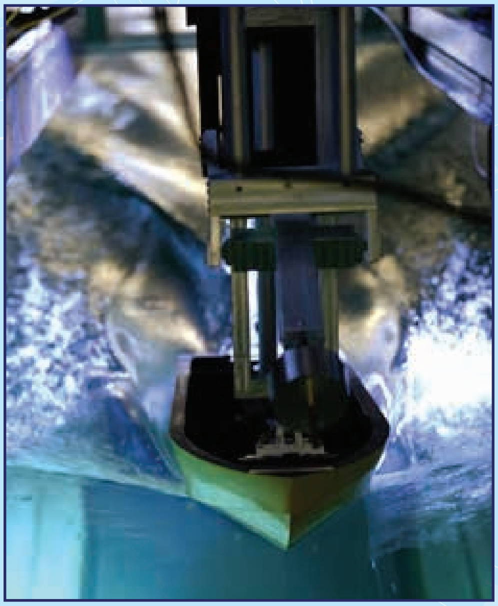
Professor:
Kevin Maki

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

University of Michgan

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

Specifically, this project is focused on how the design of naval combatants will change to expand the operational envelope to icy waters. A student team of undergraduate and master's students is working on performing model tests on ships operating in a broken ice field at the University of Michigan Aaron Friedman Marine Hydrodynamics Laboratory Towing Tank. The Office of Naval Research tumblehome model and the general purpose planning hull are being used as representative hull forms. Perforated spherical shells are used to mimic the actual floating ice. The influence of the ice on the wave resistance is being measured with a floating-beam dynamometer, and the influence on the wave field is measured with sonic wave probes.



View of General Purpose Planing Hull traveling in open water before passing through ice field.

Student team on carriage of Aaron Friedman Marine Hydrodynamics Laboratory preparing ice field for a day of testing.

Desktop Additive Manufacturing of Continuous Fiber Reinforced Ceramic Matrix Composites

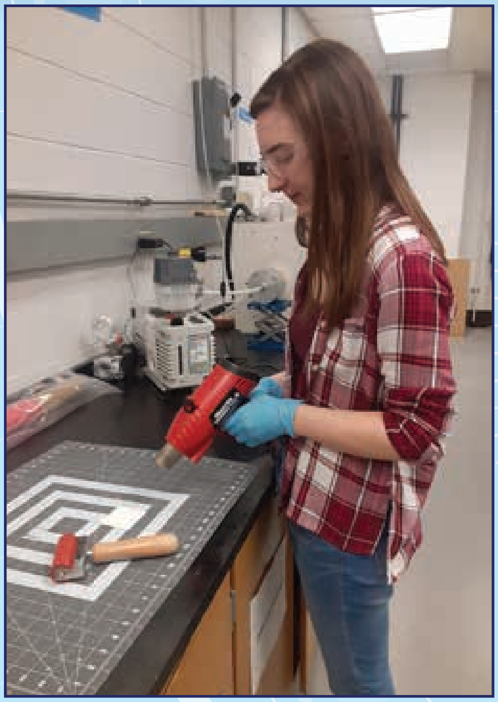
Professor:
David W. Lipke

Students:
- Master's: 1

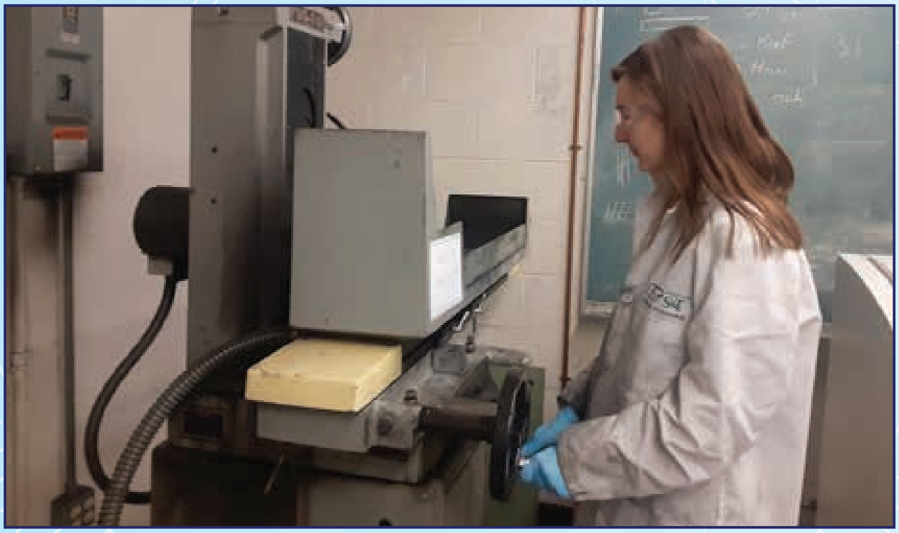
Missouri University of Science and Technology

This effort will enhance workforce training infrastructure and broaden research participation in the critical area of high temperature materials for the US Department of the Navy by establishing a structured mentorship program (CEMENTED: Ceramic Engineering Mentorship and Education) in the Department of Materials Science and Engineering at Missouri University of Science and Technology (Missouri S&T). CEMENTED will recruit highly qualified undergraduate and graduate students from underrepresented groups into the Ceramic Engineering degree program at Missouri S&T and support participants with a combination of scholarships, internships, earned salary/wages while they serve as research assistants embedded in a sponsored project and in professional development programs.

Student participants will help develop an additive manufacturing platform to produce ceramic matrix composites and improve our understanding of process-structure-property relationships for hot-structure applications. A major goal of this project is to forge recruitment-to-career placement relationships from Historically Black Colleges and Universities to several top defense contractors and to establish a mentorship model to significantly enhance diversity and inclusivity in a critically important engineering discipline enabling defense technologies.



Graduate student performs manual layup of a unidirectional continuous fiber reinforced ceramic matrix composite. Surface heating helps develop tack necessary for plies to be stacked prior to high-temperature processing.



Graduate student operates a diamond wheel surface grinder to prepare densified ceramic matrix composite specimens for characterization and testing.

NSWC Corona

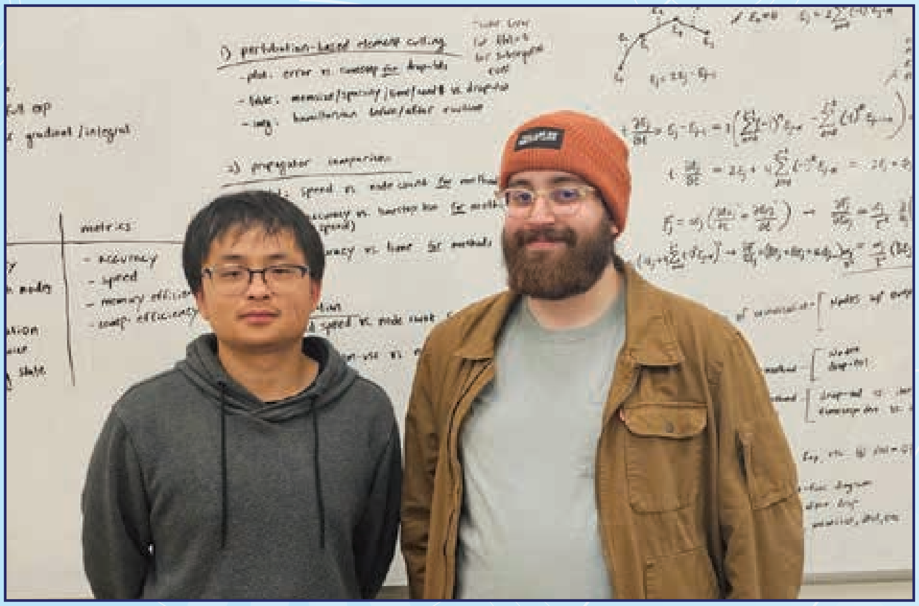
Harnessing Quantum Control Algorithms that Utilize and Enable New Machine Learning Applications with Entangled Qubits

Professor:
Bryan M. Wong

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

University of California, Riverside

This project will use quantum optimal control algorithms in conjunction with data science approaches and the broader quantum information sciences. The quantum simulations and control algorithms could have potential in advancing quantum computing that could increase the capabilities of certain calculations carried out on classical computers. 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.



University of California students.

NSWC Crane

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

Professor:
Lantao Liu

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

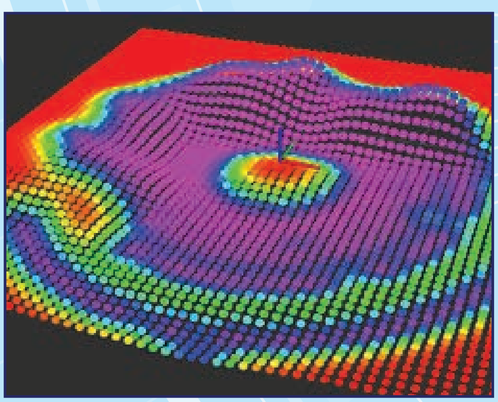
Indiana University Bloomington

The goal of our project is to develop important autonomy modules that enable an AUV/ASV to gain intelligent capabilities to cope with challenging tasks such as seafloor mapping, ocean monitoring, underwater infrastructure inspection, and unknown ocean exploration. During this past year, we have been developing solutions on robot motion planning and control, adaptive sensing, and terrain mapping. More details are as follows.

Dense environments such as those near the ocean floor contain many obstacles with only narrow paths of navigable space between them, and they are difficult for an AUV to maneuver across. To address this issue, we have been working on leveraging imitation learning and reinforcement learning to teach the robot to learn to act/move. An IU master's student, mentored by a PhD student, has been working on this topic for about half a year. To develop the learning framework, data used to train the robot must be collected. The IU student uses the state-of-the-art motion controller previously designed in our lab to guide the robot to collect useful data.

To improve the robot's decision-making capability when facing cluttered environments, we also integrate a high-level motion planner and a low-level motion controller so that we can obtain a hierarchical control structure where the low-level controller is responsible for handling complex robot dynamics and constraints, and the high-level planner is used for guidance to prevent the robot getting stuck/trapped in corners. An undergraduate student, mentored by a PhD student, is making progress in developing such an efficient and effective decision-making system to deal with tasks in dynamic and uncertain environments.

Finally, the seafloor is uneven, and the AUV navigation close above the uneven floor presents a significant obstacle because conveying changes in elevation to the AUV is difficult. To address this issue, mapping the robot's surroundings is frequently employed to determine the terrain's traversability and retain gradient data. Our research aims to improve the maps that provide traversability information to control algorithms. An undergraduate student, mentored by a PhD student, has been working on Gaussian Process (GP) elevation mapping, which is a machine learning model that estimates surface elevation based on sensor data and offers crucial gradient information for determining terrain traversability.



Undergraduate student working on elevation map reconstruction. The pictures show the student working on the simulation environment.

Master's student working on ASV and mobile robots.

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

Professor:
Andrew Lukefahr

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

Indiana University Bloomington

This proposal offers to design and build Independent Functional Testing (IFT) tool suites for field-programmable gate arrays (FPGA) using a two-step process. As the architectural details for many FPGAs are undocumented, we will first utilize reverse-engineering techniques to determine exactly 'what to test'. Next, we will address 'how to test'. Unlike traditional functional testing approaches, our method will rely on simple unit testing and dynamic partial reconfiguration to exercise the FPGA fabric without highly-customized and non-portable test vectors.

Image courtesy of Defense Visual Information Distribution Services.

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

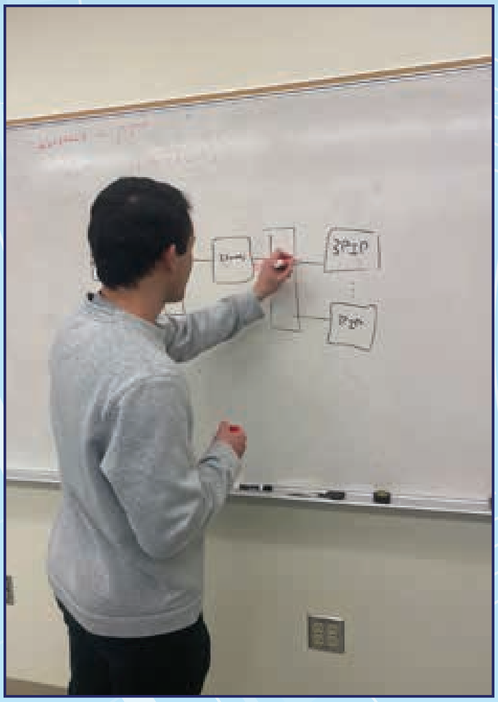
Professor:
Amro Awad

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

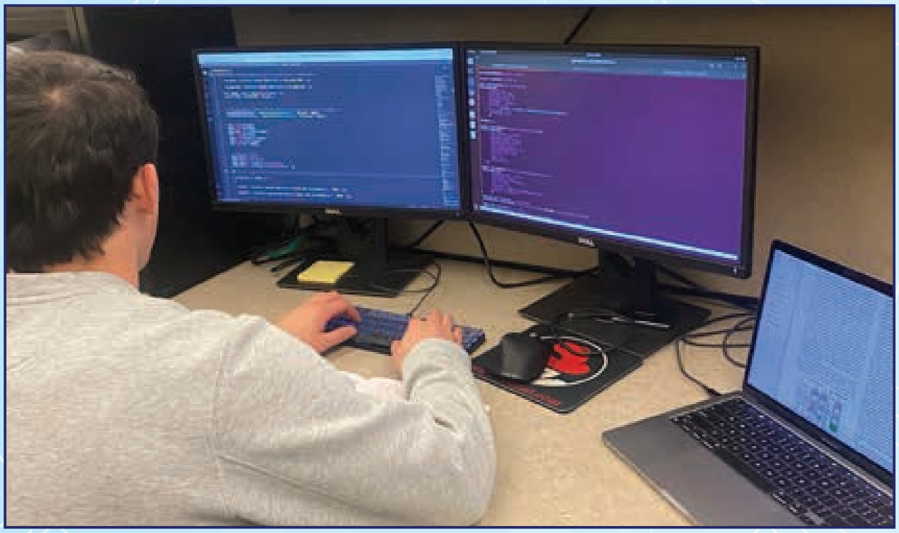
North Carolina State University

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

The project will ultimately include 2 to 3 PhD students and is planned for the period of October 2022 – October 2025.



Discussing ideas for projects.



Implementing a proposed architecture.

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

Professor:
Eric Matlis,
Aleksandar Jemcov,
Thomas Corke

Students:
- PhD: 1

University of Notre Dame

Transition to turbulence for cones or lifting bodies at angle of attack in hypersonic flows is influenced by the development of both Second Mode and cross-flow boundary layer instabilities, which may exist simultaneously at intermediate yaw angles. Potential interactions between these two mechanisms can accelerate transition. Turbulence transition has a critical impact on surface heat flux, which can increase by a factor of five compared to laminar boundary layer heat flux rates. Transition due to Second Mode instabilities can be suppressed with nose bluntness, while cross-flow dominated transition can be suppressed with the use of discrete roughness elements applied to the surface. This work is investigating the potential for interactions, which will provide the framework for transition prediction.

Initial investigations using simulations have identified the frequencies of interest in both the Second Mode and cross-flow instabilities. These simulations began with the calculation of the mean base flow at angles of attack from 2 deg to 4 deg on a 7-deg half-angle right circular cone. The data from the mean flow calculations is being used to drive the calculation of the linear stability by using a parabolized stability code.

Preparation is underway for experiments that will be conducted at the US AirForce Academy's Mach 6 Ludwieg tube. The model geometry will match that used for the simulations and is 20 inches in length. Unit Reynolds of 10M/m will be used. The experiments will include off-wall measurements to document the instability development in the boundary layer as yaw angle is varied.

Based on the understanding derived from these simulations and experiments, mechanistic approaches to transition control will be developed using combined bluntness and surface roughness. The practical impact for the Navy is in the design of hypersonic vehicles that will inevitably experience transition by the same mechanisms studied in this program. The knowledge gained from this approach will reduce the thermal requirements on materials, apertures, and sensors located aft of the vehicle nose cone.

Student setting up an experiment in the Hypersonics Quiet Wind Tunnel Facility.

NSWC Crane

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

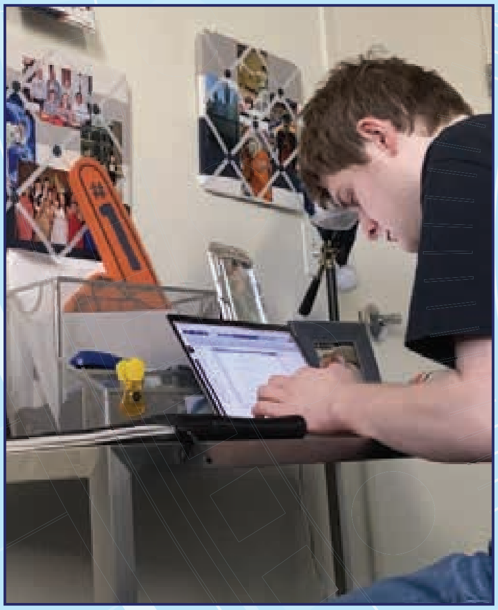
Professor:
Daniel DeLaurentis,
Shreyas Sundaram

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

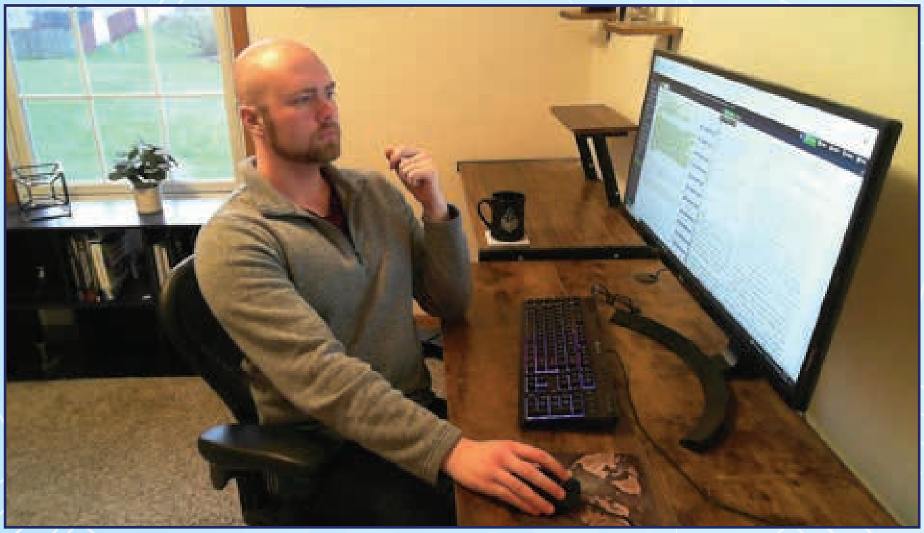
Purdue University

This Purdue NEEC project advanced the modeling and simulation techniques for hypersonic flight system-of-systems by identifying how operational dependencies between guidance, navigation, and control subsystems create vulnerabilities in a degrading vehicle. This was done by implementing a custom simulation environment to run an example mission in a variety of failure modes and analyzing these simulations using System Operational Dependency Analysis. From the work, the impact of specific component faults on vehicle performance was found for an example mission, and a generalizable method of mapping guidance, navigation, and control subsystem failures to vehicle performance was created and validated.

As a result of the partnership between NSWC Crane and Purdue, significant contributions to modeling and simulation techniques for hypersonic glide missions were made, in addition to developments in techniques for quantifying the stability and optimality of their components. By leveraging and extending the work performed in this project, the Navy enhances their ability to perform high-quality, vehicle-level trade studies during the costly and rapidly changing development cycle of hypersonic vehicles and reduce the risk associated with such systems.



Purdue University student analyzing Hypervelocity Flight System data.



Purdue University student developing models for Hypervelocity Flight System experimentation.

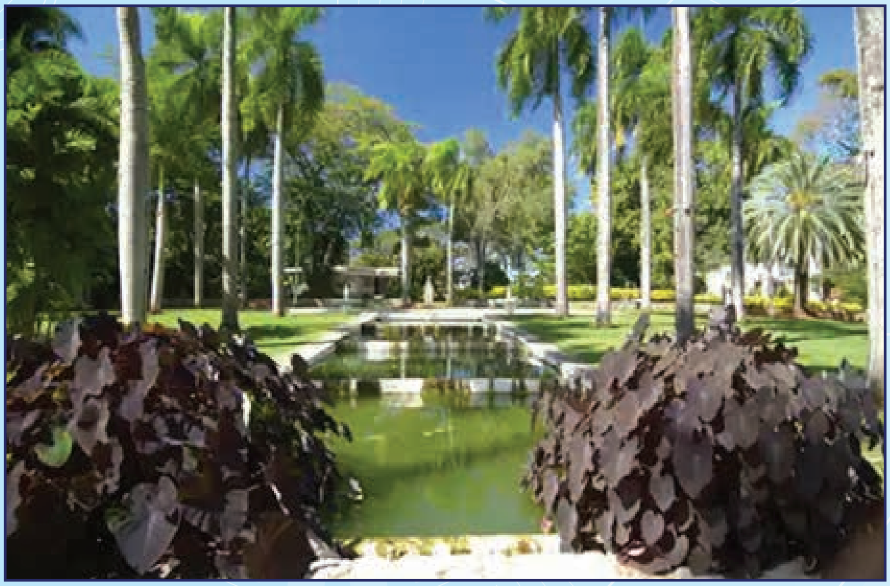
DCP: Improving Virtualized Data Center Resource Efficiency Using Dynamic Container Placement Strategies

Professor:
Emmanuel Arzuaga

Students:
- **Undergraduate:** 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 the performance and power consumption of containerizing virtual machines (VM) 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.



University of Puerto Rico - Mayaguez.

Dielectric Breakdown in High Voltage Power Systems

Professor:
David A. Wetz

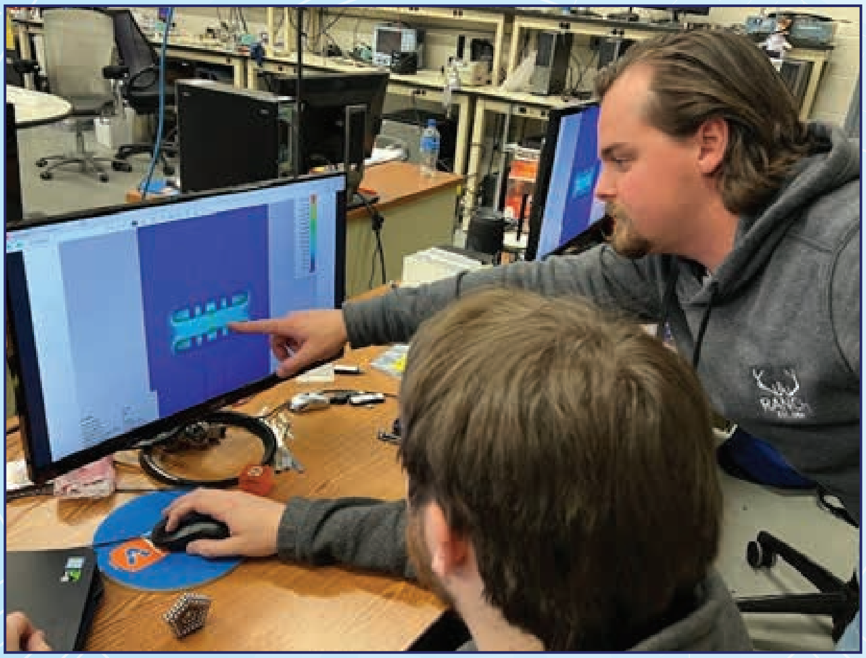
Students:
- Undergraduate: 1
- PhD: 3

University of Texas at Arlington

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

Student works on measuring the dielectric permittivity of epoxy samples with and without nano particle additives.

Student prepares molds for making epoxy samples with and without nano additives.



Students work on electromagnetic modeling of dielectric materials with and without nano particle additives.

Energy Storage and Dielectric Insulator Reliability and Safety in Future Naval Power Systems

Professor:
David A. Wetz

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

University of Texas at Arlington

This multifaceted effort is aimed at studying high voltage dielectric insulators in high voltage pulsed power systems and the safe integration of energy storage in next generation naval power systems. In the related NEEC project, unique potted dielectric materials and mixtures that can grade the electric field smoothly between materials of varying permittivity to reduce field enhancements and the probability of breakdown are being identified, modeled, fabricated, and studied experimentally under pulsed electric fields. A high voltage pulsed power testbed has been set up and is being used to characterize the pulsed dielectric strength of potted and thermoset plastic dielectric materials with the aim of producing replacements for transformer oil in the near term. In this NEEC project, the incident energy that results from the short circuit of electrochemical energy storage devices is being modeled and experimentally verified. As the Navy begins to integrate high voltage energy storage devices into their labs and ships, potential arc flash events pose a significant risk to the electrical workers that must maintain them. This work is aimed at better characterizing these dangerous events so that proper personal protective equipment requirements can be established and employed. A related effort is aimed at characterizing electrical generators that have multiple output windings and employ mechanical flywheel energy storage to maintain inertia during high power transient load events. Successful employment of kinetic energy, in the form of high-speed rotational energy storage, will buffer the dynamics of transient loads while adding volumetric and scalability benefits.

Students set up an arc flash experiment in which a high voltage electric double layer capacitor is being studied.

Student works on electromagnetic modeling dielectric insulator materials with and without nano particle additives.

Students work on installing a flywheel energy storage system into motor-generator set.

Logistics Algorithm Development for Quantum Computers (LAD-QC)

Professor:
Thomas Krauss

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

Virginia Polytechnic Institute and State University

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

The goal of the Logistics Algorithm Development for Quantum Computers project is to demonstrate the potential efficacy of quantum algorithms for the Quadratic Assignment Problem by building on the existing, demonstrated theoretical quantum algorithms for route optimization and to develop QAP quantum formulations suitable for execution on quantum hardware. The proof-of-concept quantum formulations will demonstrate a reduction in complexity for specific cases of the QAP. Multiple architectures of quantum computing will be evaluated, including quantum annealing, gate based, and analog (e.g., neutral ion), allowing for understanding of the applicability of the architecture to the logistics problem. This will also provide students with direct exposure to problems of national interest, access to quantum computing hardware including the IBM Q and D-Wave 5000Q machines, and develop real-world experience in quantum application development. These programs will be geared toward enhancing students' essential skills to enter the national security workforce by establishing multiple student teams whose tasks are to develop novel research that solves a specific naval need.

Virginia Tech student research team.

NSWC Dahlgren

Data Fusion for Ship Wake Detection

Professor:
Justin Kauffman

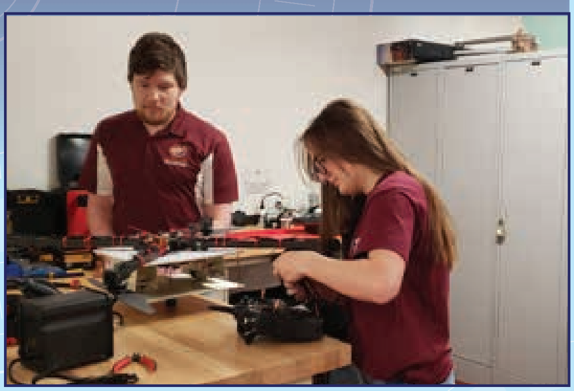
Students:
- **Undergraduate:** 2
- **PhD:** 1

Virginia Polytechnic Institute and State University

The team is investigating multiple methods for fusing ship wake data to increase the probability of detecting ships based on their wakes. Research areas actively pursued in this project include identifying ship wakes in real-world synthetic aperture radar (SAR) data using radon transforms, data fusion algorithms of infrared (IR) and SAR+IR imagery, uncertainty qualification (UQ) of wake classification models, and different data augmentations to have our synthetic data be more representative of real-world data. The team is also working on implementing over-the-horizon radar simulations and simulating additional ships in formation; while these simulations increase data complexity, they have the potential to allow the fusion and classification models to recognize the number of present ships. The outcomes from this research investigation are expected to have high relevance to the Navy and Joint Services mission spaces. Increased awareness and characterization of the electromagnetic environment directly impacts the increased relevant and actionable information for commanders. For the specific application of ship wake detection, the sensor and data fusion algorithms are being rigorously tested and assessed for increased probability of detection and decreases in false alarms.

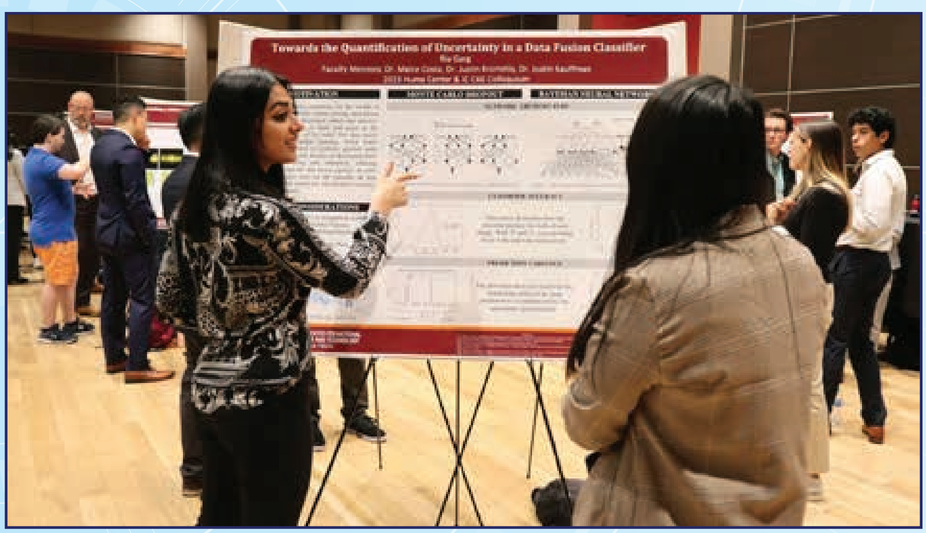
Building the IR and SAR+IR data fusion algorithms enabled the team to establish baseline metrics while also studying operational conditions that mimic omission or degradation of input streams through data augmentations. The team produced various noise profiles, simulated sensor dropout and malfunctions, and published the results at AIAA SciTech in January. The IR and SAR+IR data fusion work will be highlighted in Erik Higgins's PhD dissertation, while the augmentations for sensor dropout were presented in the AIAA SciTech paper.

The team has worked on the UQ of the classification models by obtaining baseline results for single SAR band wake and no-wake classifications before moving on to multiple SAR band inputs. Through diagnosing model behavior issues during the UQ effort, the team gained insight into the classification model and is making progress with UQ through two different UQ approaches: Bayes neural networks and UQ via dropout. The team has diagnosed the model behavior issue and is working to publish the results in the summer of 2023.



PhD Candidate Aerospace Engineering and third-year Ocean Engineering Major working with a custom drone with a cheap, mounted synthetic aperture radar (SAR) camera that the team built.

Third-year Ocean Engineering Major and PhD Candidate Aerospace Engineering present their custom remote controlled ship and custom drone with mounted SAR camera to be used to collect real-world data with a slide in the background demonstrating our application.



Fourth-year Aerospace Engineering Major presenting work related to uncertainty quantification of the data fusion classifier to third-year Ocean Engineering Major at the 10th Annual Hume Center & IC CAE Colloquium held at Virginia Tech.

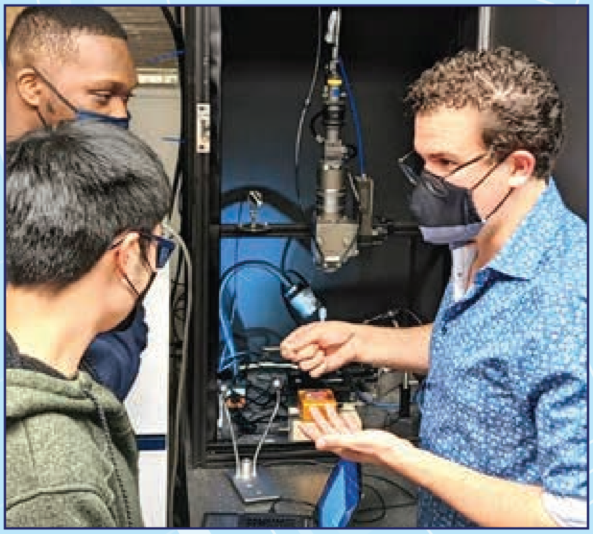
High Power Laser Studies of Thermal Oxidation and Ablation Properties of Ceramic Matrix Composite Materials for Hypersonic Application

Professor:
Mool C. Gupta

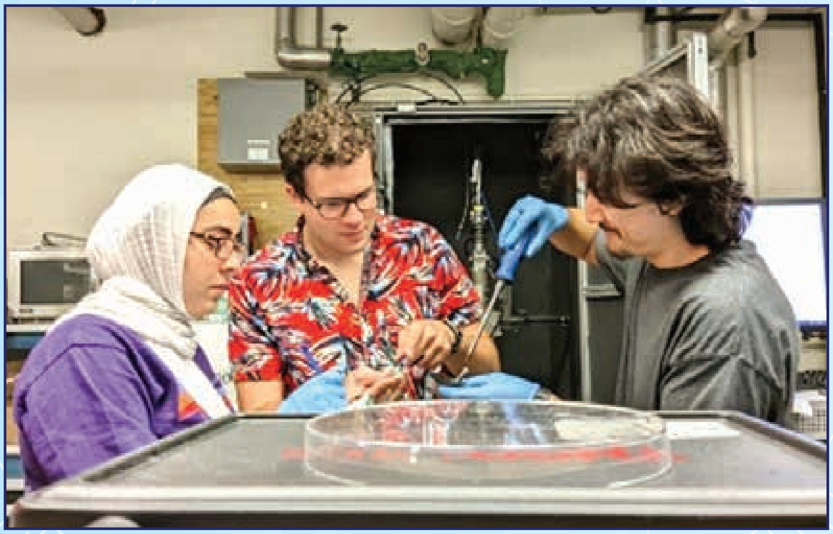
Students:
- Undergraduate: 5

University of Virginia

Thermal protection systems are required for ballistic re-entry of 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. To protect the leading edge, ceramic matrix composite materials like carbides, borides, and nitrides of Zr, Hf, Ta have been investigated. However, significant degradation of material through oxidation and ablation could occur under extreme temperatures produced when a hypersonic vehicle traverses through an atmosphere. Heat flux values of 1500–2500 W/cm^2 are encountered. A complex experimental setup is required to generate such high heat fluxes and evaluate the material oxidation and ablation rates. We are carrying out experiments on laser oxidation and ablation methods 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. Currently, modeling and simulation are carried out to estimate the oxidation and ablation rates. The laser oxidation and ablation experiment results will allow the validation of models and easy screening of different test materials for future performance improvement. The data generated would provide the limitations of current materials systems as well as the development of protection against laser threats. We are investigating the fundamental physics of surface chemistry through spectroscopy and analytical techniques. The laser oxidation and ablation studies are carried out under different atmospheric conditions and pressure. The PI has a 4000-watt power laser in his laboratory, so the desired heat fluxes are easily achievable. The ceramic matrix composite samples were laser micromachined, and the laser processing parameters such as laser power, scan speed, beam overlap, and surrounding atmosphere were varied. The laser-processed sample morphology was characterized by a scanning electron microscope. The project is providing educational training to students in the areas of lasers, optics, and photonics and has developed stronger research collaboration with Dahlgren engineering staff.



University of Virginia NEEC students.



Students conducting experiments.

Deep Learning-Based Target Tracking and Assignment for Cooperative Swamp Defense

Professor:
Ju Wang

Students:
- **Undergraduate:** 6
- **Master's:** 2
- **PhD:** 1

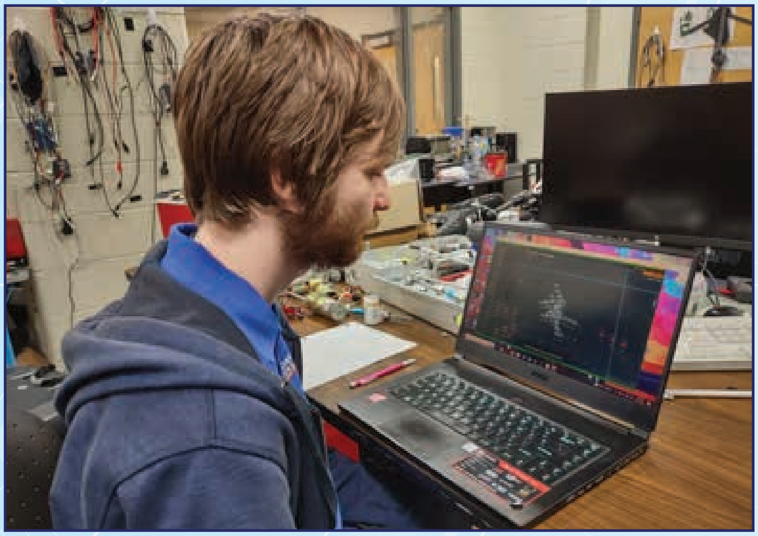
Virginia State University

We are developing a machine learning system that can estimate the 6-degree pose of moving objects and provide real-time engagement assistance against enemy threats. The system will provide critical capabilities in target tracking and target engagement support for close range defense. The 6-degree AI solutions utilize a fast GPU to provide real-time monitoring of potential threats (boat, aircraft). This information improves Battlespace Awareness and makes it possible for semi-automated fire control, which is especially important when facing swarm attack.

The centerpiece of the AI algorithm is a 156-layer deep neural network. The network is further divided into two stages: the first stage is the deep feature extraction pipeline, and the second stage is the regression stage. The deep feature pipeline stage consists of a shared core and a long short-term memory (LSTM) network, which allows the network to process a sequence of video frames to obtain high-confidence results. To train our deep neural network, we developed a 3D Unity game to create realistic scenarios to generate synthetic imagery data and ground truth data. The trained network is capable of providing good orientation estimation for enemy threats smaller than 100 pixels on screen, or roughly a few kilometers away. When combined with optically magnified images, the system can easily be used to track targets 10 miles away.

Another component of our system is the reinforcement learning-based target assignment algorithm. This algorithm will provide real-time decision-making capability for engagement of a large number threats in a complex combat mission. The algorithm uses the input information, such as threat position, type, and velocity, to determine the actions of the asset ships. Our method uses knowledge embedding to incorporate domain-specific knowledge in the decision algorithm. The algorithm is trained with scenario data generated by a game engine that can generate realistic thread behavior.

Virginia State NEEC students.



NEEC student working on AI algorithms.

NSWC Indian Head

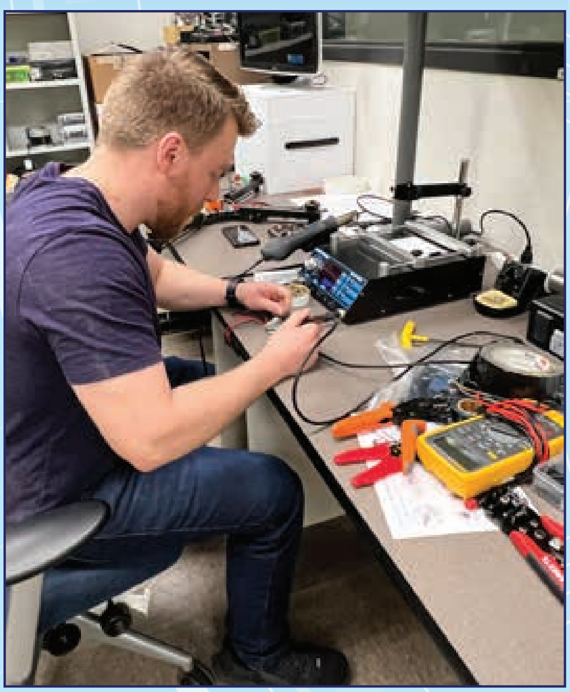
In-Ear Wearable Device (EWD) for Predicting Warfighter Readiness

Professor:
Sangram Redkar

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

Arizona State University

The EWD is a lightweight, modular, self-contained, battery-operated, physiological sensing device for accurate and real-time monitoring of warfighter health state during peace or battlefield conditions. The system consists of an ear wearable sensor system that measures physiological signatures and a (data acquisition) DAQ system to control and operate the device and collect, store, and analyze acquired physiological data of the wearer. The sensor system weighs 15 grams and fits in the ear of the wearer like an earbud. The device does not interfere with the operational tasks of the warfighter and provides alerts when physiological measurements are not normal. The EWD (hardware and algorithms) is compact and customized to detect the onset of an adverse or degrading health state of the warfighter and can assist in remote warfighter readiness assessment and operational decision-making. This project focuses on developing and evaluating the efficacy of customizable EWD hardware and algorithms to detect the onset of autonomic-bio-chemical (ABC) responses to a warfighter's health state and to provide remote warfighter readiness assessment capabilities.



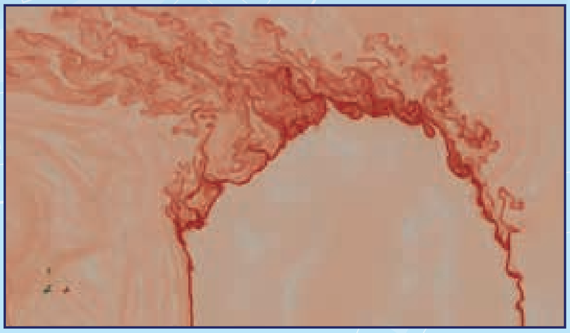
Student and Sangram Redkar, "Embedded Heart Rate Estimation Through Machine Learning, Application, Comparison, and Limitations" (in review), IEE Sensors Journal.

Student and Sangram Redkar, "PBVI for Optimal PPG Noise Filter Selection Using Activity Recognition Observations for Improved Heart Rate Estimation on Multi-Sensor Systems" (in review), ASME Journal of Medical Devices, on shock-droplet interactions.

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

Professor:
Prashant Khare

Students:
- PhD: 2



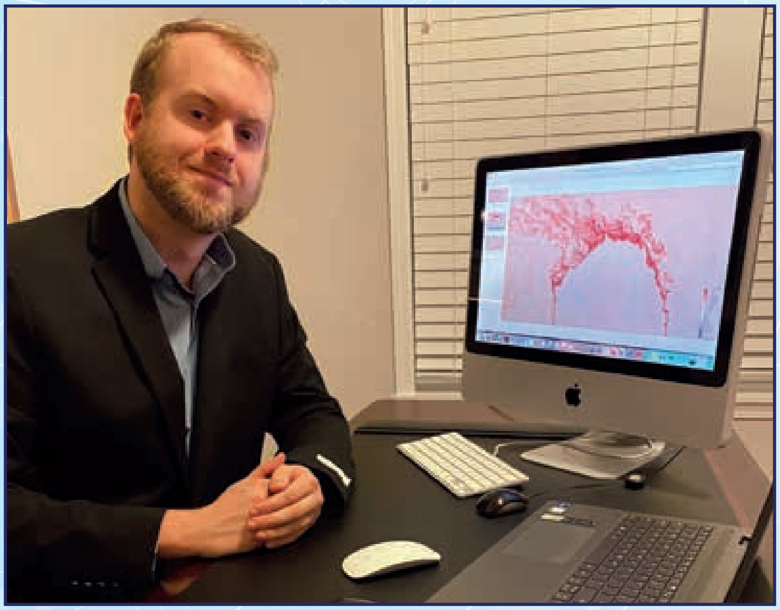
Interactions between shock wave traveling at a Mach number of 2.4 and a water droplet (contours show density gradients).

Interactions between shock wave traveling at a Mach number of 1.47 and two water droplets separated by a distance of 6.8D (contours show density gradients).

University of Cincinnati

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

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



Student working on shock-droplet interactions.

Dynamic Gas Generation through Microporous Nitramines

Professor:
Veronica Eliasson

Students:
- Undergraduate: 13
- PhD: 1

Colorado School of Mines

The problem is simple: how to pack as much high-energy propellant as possible into a defined volume. The solution, however, is not so straightforward. The rate at which the propellant releases energy must be carefully controlled if the projectile is to be efficiently propelled out the barrel. If energy is released too slowly, performance is needlessly wasted; projectiles are launched at slower velocities and effective range is reduced. If the propellant is burned too quickly, the rapid release of energy leads to pressure spikes that can damage or outright destroy equipment. This effort seeks to employ novel porous energetic materials to realize tailorable gas generation through the selective deposition of high-porosity explosives. The hypothesis is two-fold: (1) the concentration of porous energetic materials in a defined volume can change the apparent burn rate of the propellant without the need for perforations, and (2) an energetic binder will be consumed at a rate faster than adiabatic compression can occur. Combining these hypotheses with additive manufacturing, we believe monolithic high-energy density gun propellants with optimized gas generation rates can be produced.

The Explosives Research Laboratory at the Colorado School of Mines is dedicated to training students in the safe practices involved with energetics synthesis, manufacturing, and characterization. Students leaving our group will enter the workforce possessing skills such as small-scale sensitivity training, closed bomb pressure generation analysis, ultra-fast high-speed photography, safe blast range operations, and an understanding of small- and large-scale applied shock physics as we continue to grow and improve our world-class facilities. All students are required to attend one year of explosive engineering coursework that provides students with both classroom and hands-on explosives education. Students passing these classes are trained in explosives handling safety, explosive train design and fabrication, rock fragmentation, explosive experimental design and execution, basic explosive chemistry, and designing explosives for efficient combustion. Our goal is to establish a workforce pipeline of professionals capable of entering the explosives industry with enough experience to produce meaningful results while saving laboratories and companies a significant investment in time and training.

Students learning how to carefully work with explosives.

Understanding explosives.

Explosives laboratory.

Embry-Riddle Aeronautical University

Deep Learning-Based Target Tracking and Assignment for Cooperative Swamp Defense

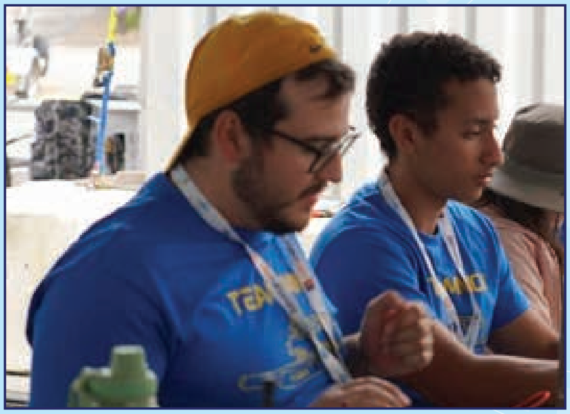
Professor:
Eric Coyle,
Patrick Currier

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

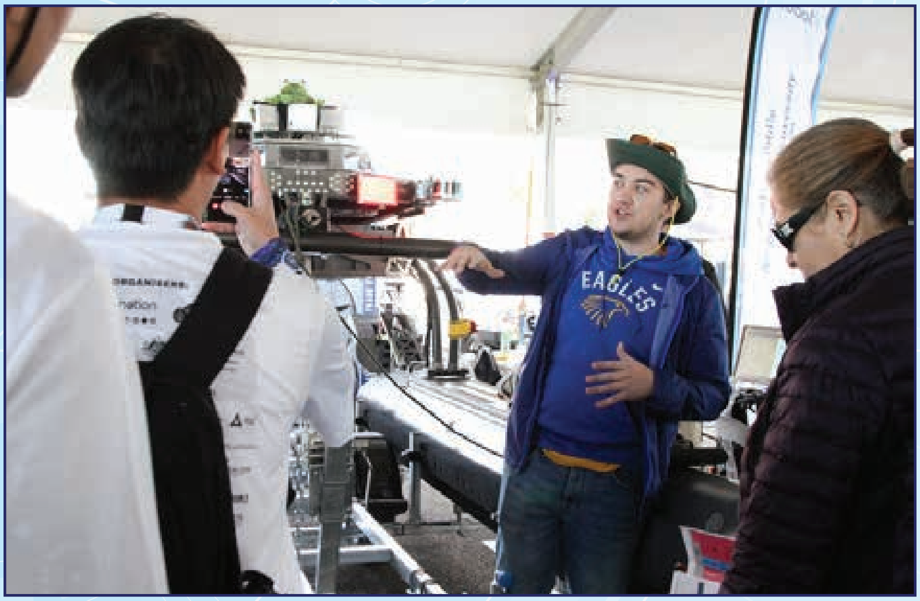
This project focuses on providing situational awareness to autonomous surface vessels (ASVs). Situational awareness is the ability to perceive objects and comprehend events in the surrounding environment. The research will provide increased situational awareness for applications such as patrolling in-water test ranges and harbor security by providing multi-modal data sets and data fusion processing techniques necessary to autonomously detect and identify objects in the littoral environment. The project strategy focuses on techniques that leverage spatial and visual data. For the spatial analysis, the research focuses on object segmentation, mapping, tracking, and classification using point cloud data representations, while visual data is analyzed using detection and segmentation neural networks. These tools lead to intelligence, surveillance, and reconnaissance (ISR) capabilities, including the detection and classification of vessels, hazards, and wildlife. Strategies developed later in this research will look to fuse these modalities for increased robustness.

Current progress includes completion of a tagging scheme to identify and categorize detected objects of interest based on Navy needs. The tags describe movement, object domain (ground, aerial, surface, underwater), and if the object is natural or man-made. To date, the team has labeled 3300 images for its object detection dataset and 400 images for its segmentation dataset by using the described tagging scheme. Preliminary results show the best performance when YOLOv5 is used for detection and Inceptionv2 is used for segmentation networks, though hyperparameter optimization is ongoing. The spatial data processing techniques for object detection, classification, and mapping have been implemented in simulation, tested on the platform in real-time, and modified to leverage multiple observers. For real time testing and data collection, the team uses a wave adaptive modular vessel (WAM-V), called Minion. The team spent a full week testing these situational awareness methods and an autonomous tasking scheme that leveraged their outcomes at the 2022 Maritime RobotX Challenge, in Sydney, Australia. The team took first place, largely due to the success of these methods. The team is also working on a vehicle agnostic data acquisition mount so the tools used on Minion can be tested on other vessels.

Student shows the spatial data classification scheme to vehicle inspection judges at the Maritime RobotX Challenge 2022.



Students working on image detection models during Maritime RobotX Challenge.



Student describes the ASV's perception suite to vehicle inspection judges at Maritime RobotX Challenge 2022.

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

Professor:
Jeff McGough

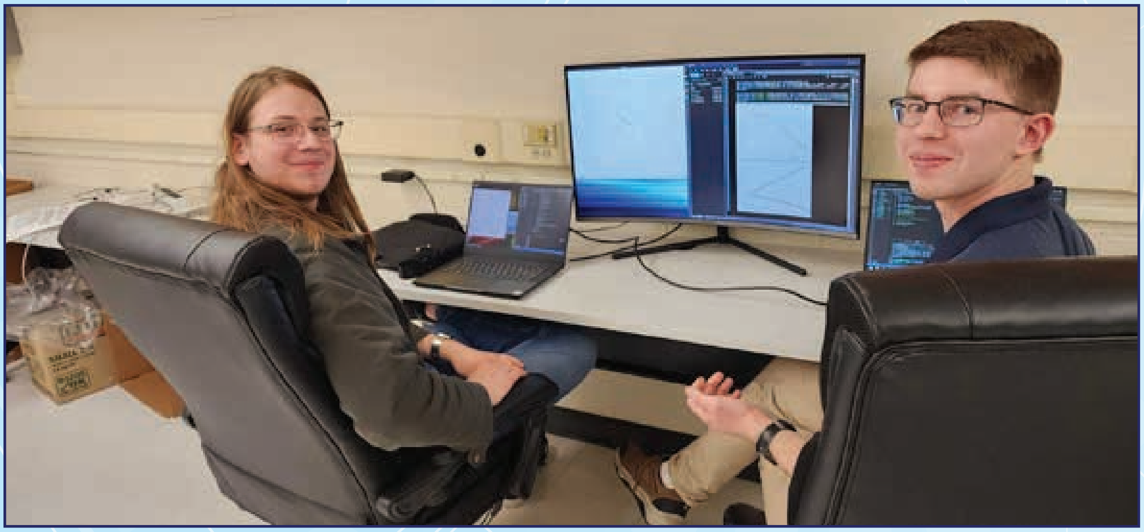
Students:
- Undergraduate: 3

South Dakota School of Mines and Technology

Localization and mapping in GPS-denied environments is difficult to achieve. It is even more challenging when ranging, inertial measurements, or landmarks are compromised. A search of the literature produces a diverse set of approaches. Missing from these is a framework to compare different methods using the same standards for each approach.

The first goal of this project is to develop the framework and the assessments to compare the effectiveness of localization and mapping algorithms no matter how different they may appear. Incorporation of traditional software engineering testing and validation will be employed as well as development of assessment rubrics for semi-autonomous or fully autonomous missions. There are many ways that one can assess the effectiveness of an autonomous mapping algorithm. Initial comparison will use predetermined paths and will use strict metrics for comparison. Later comparisons using exploratory algorithms will require the development of new and appropriate rubrics to assess performance. Metrics will include map fidelity, mission duration, exploration effectiveness, agent observability, fiducial recognition, memory, CPU and networking requirements, and more.

We plan to compare the previously developed SLIM (self-localization and intelligent mapping) algorithm, the set of traditional methods such as particle-filter based SLAM, EKF-SLAM (extended Kalman filter simultaneous localization and mapping), and the tools in ROS. ROS, the Robot Operating System, has a set of mapping tools such as Gmapping and Hector SLAM that are effective in many applications and can act as the benchmark.) Some of the approaches are for a single agent. These need to be modified for multiagent localization and the sensory deprived target environment.
The winning algorithm should perform on embedded hardware with sensors capable of operating underwater. Ultimately, we are attempting to create an algorithm for autonomous underwater mapping with multiple agents. We should be able to network the different agents together, determine a near-optimal path for each of the actors to efficiently and collectively map the unknown space, and do so quickly without observation and with the sensors available for underground, underwater systems.



Students analyzing algorithms.

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

Professor:
Monifa Vaughn-Cooke

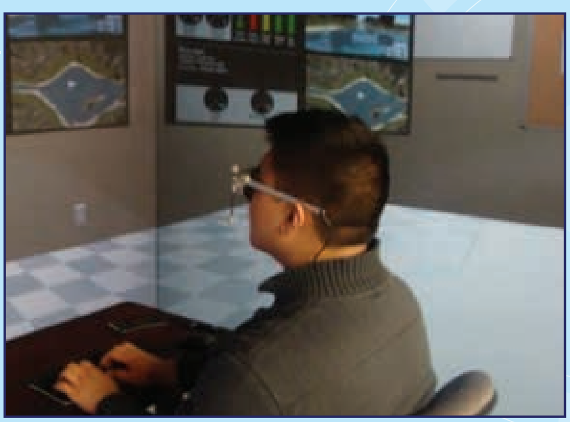
Students:
- **Undergraduate:** 6
- **Master's:** 3
- **PhD:** 2

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 by improving system safety. In addition, recommendations for standardized metrics will be defined to integrate into system design validation activities to determine whether 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.

The UMD Virtual Reality CAVE.



NEEC student analyzing new algorithms.

NEEC students in the Virtual Reality CAVE.

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,
Yuri Rzhanov

Students:
- **Undergraduate:** 20
- **Master's:** 6
- **PhD:** 4

KRILL (Keyport UUV) Team During Testing Demo.

University of New Hampshire

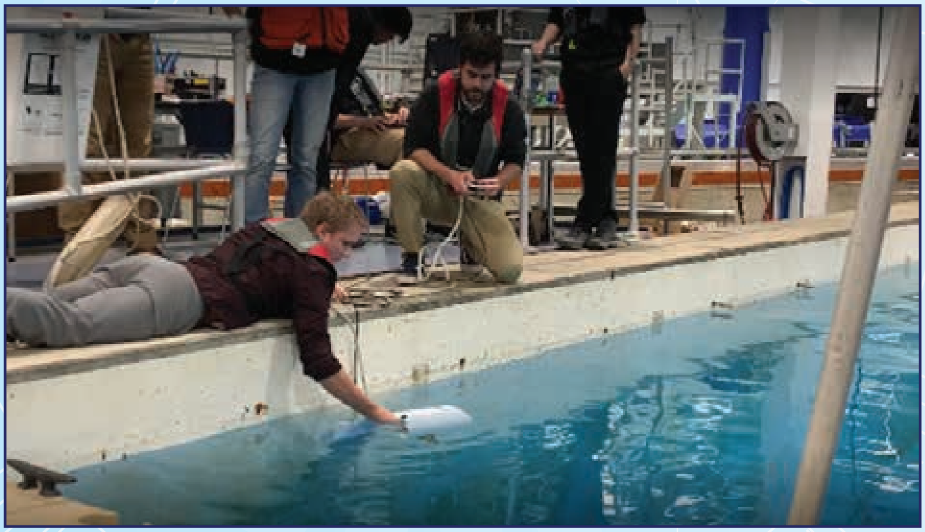
Autonomous vehicles and autonomous systems continue to be a major emphasis for research and development by the US Navy. The DoD Third Offset strategy, numerous technology roadmaps, and many strategic vision documents from the Chief of Naval Operations through the Office of Naval Research all emphasize the importance of using uncrewed vehicles in support of the military. The need for research dedicated to reliable autonomy methodologies include those for multi-objective optimization and velocity obstacles.

The PIs at the University of New Hampshire (UNH) and the Marine And Naval Technological Advancements for Robotic AutonomY (MANTA RAY) Team continue to develop technologies to enable robust marine vehicle autonomy. For this work, the UNH team addresses these US Navy autonomous vehicle issues by focusing on the development of both a simulation and a low-cost experimental testbed environment for evaluating autonomous perception. The three main research goals are:

(1) to develop a simulation testing environment to analytically observe and predict unmanned underwater vehicle (UUV) perception capabilities and its performance on overall system autonomy

(2) to further develop an experimental multi-vehicle test platform:
(2A) in which UUV perception and autonomy capabilities may be physically tested
(2B) from which a low-cost sensor system to enable autonomous coordination of multiple UUVs can be developed and implemented

(3) to develop an AI-based metric system (via fuzzy logic and fuzzy set theory) to numerically evaluate vehicle autonomy performance.



Ghost Uncrewed Performance Platform Submersible (GUPPS = Robotic Fish) Team During Testing Demo for GUPPS IIB.

Artificial Intelligence Models for Predicting Supply Chain Failures and Their Impacts

Professor:
Hugh Medal (PI)
Mike Sherwin (Co-PI from Duquesne University)

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

University of Tennessee, Knoxville and Duquesne University

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

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

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

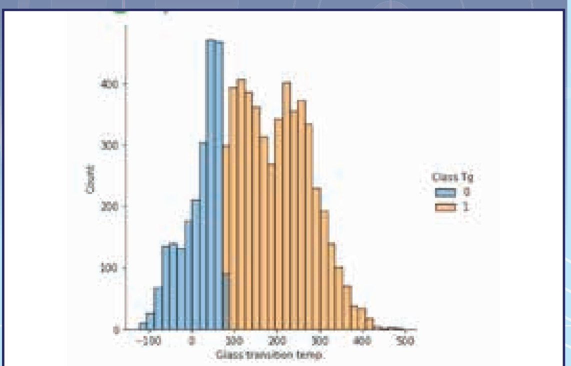
For the mitigation phase, we are developing tools to help decision-makers make better decisions related to design refresh planning. Specifically, we are develop a model to help determine how often a system should undergo a design refresh, which parts should be included in each refresh, and when mitigation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

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

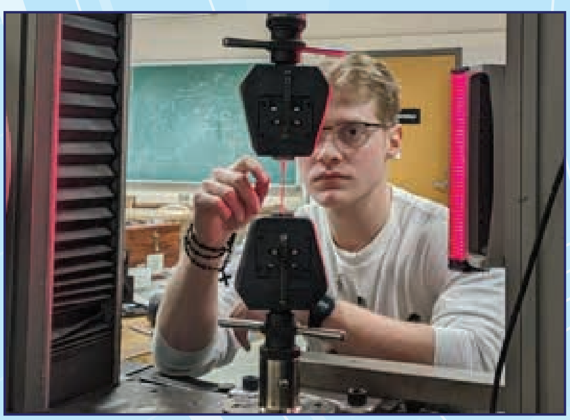
Toward the Design of Polymers for Additive Manufacturing with Resistance to Marine Environment Degradation: A Data Science Approach

Professor:
Navid Zobeiry,
Dwayne Arola

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



Higher Tg (orange) desired



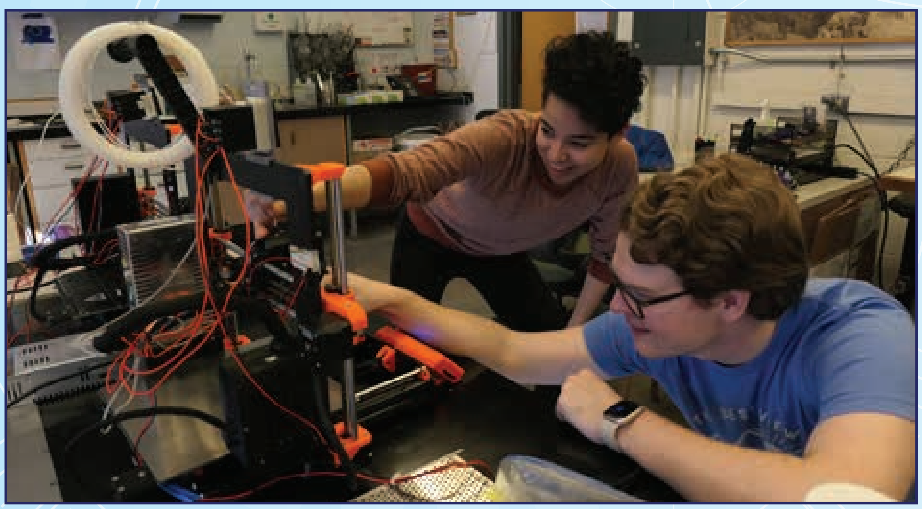
NEEC student analyzing data.

University of Washington

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

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

Owing to their superior strength to weight ratios, fiber reinforced polymers (FRPs) could play an important role in the future of naval unmanned surface and undersea vehicles. However, there are challenges to 3D printing of FRPs, which can result in defects that exacerbate the potential for accelerated degradation under marine conditions. Therefore, the team is also pursuing complementary activities. Specifically, the team is evaluating the printability of both experimental and commercial composite filaments for FFF (fused filament fabrication) with continuous fibers and quantifying the quality and reliability of the printed material. The next steps are to advance the capability for printing these materials by using robotic systems for manufacturing composite structures and characterizing the resulting structural integrity of printed forms. Potential approaches include the scalable composite robotic additive manufacturing (SCRAM) system developed by Electroimpact and using Advanced Fiber Placement (AFP) of tape materials. The last critical step involves experimentally evaluating the durability and hydrodynamic characteristics of selected thermoplastic composites after AM processing after prolonged marine exposure.



Students running experiments.

Mechanical Obsolescence Management: Risk-Based Analysis and Prediction

Professor:
Christina Mastrangelo

Students:
- **Undergraduate:** 7
- **Master's:** 1
- **PhD:** 1

University of Washington

Obsolescence occurs when a given part is no longer procurable. This causes problems for organizations, particularly those that manage long-lived systems. When a part in these systems experiences obsolescence, a plan must be developed to keep the system operable. In order to give decision-makers more time to develop plans to adapt to obsolescence, this project is working toward a proactive strategy to obtain a likelihood for an end-of-life obsolescence 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 component lifecycle, and combining that with predictive modeling for hardware or mechanical parts. The result is potential new insights or features that will allow obsolescence management to continue to move from a reactive to a proactive approach, addressing problems before they occur. In this reporting period, the team is collected and analyzed 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™). The team also implemented an oversampling technique to accommodate the small sample sizes that occurred with mechanical data. The team also developed, tested, and implemented an approximate confidence interval for the likelihood of obsolescence prediction.

NEEC students at NUWC Keyport.

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

Professor:
Ashis G. Banerjee,
Santosh Devasia

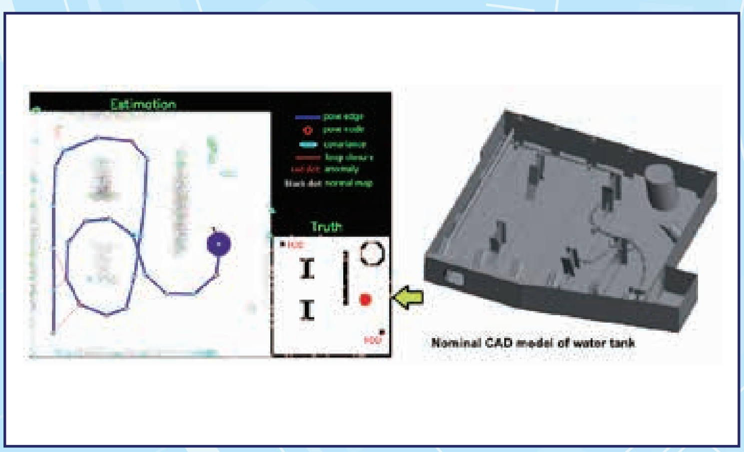
Students:
- **Undergraduate:** 8
- **Master's:** 1
- **PhD:** 1

University of Washington

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

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

Therefore, instead of using a single customized robot, we are building a low-cost, decentralized heterogeneous robot network that will be deployed with human assistance. Inter-robot communication and communication between the robots and remote human supervisor(s) are expected to be unreliable and will be limited to key information sharing. Noting that human supervisors will have prior knowledge of the inspection tasks, the networked system will primarily solicit their assistance in positioning the robots initially at suitable locations. Once positioned, the robots will automatically navigate and explore their neighboring regions. Consequently, the humans will only need to intervene under two circumstances: 1) reposition the robots if they have finished their allocated tasks, and 2) assess the significance of the anomalies identified by the robots.



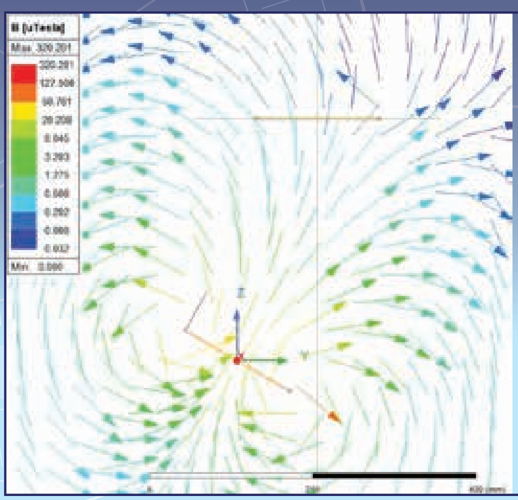
Active exploration of a confined space by an autonomous ground robot (in simulation) for detecting anomalies such as foreign object debris (FODs), corroded structures, and damaged components.

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

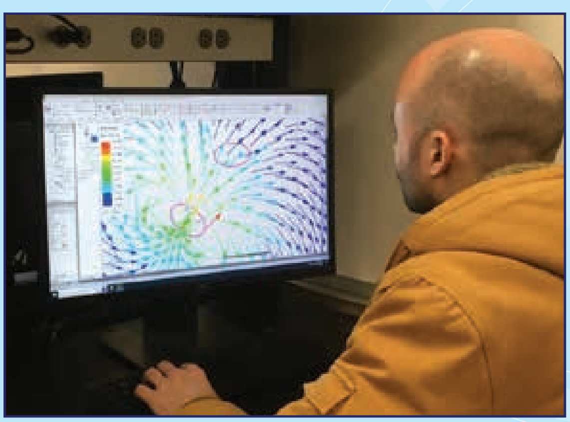
Magnetic Induction Communication for Unmanned Underwater Vehicles

Professor:
Murari Kejariwal

Students:
- Undergraduate: 7
- Master's: 1
- PhD: 1



Ansys simulation for magnetic field vector.



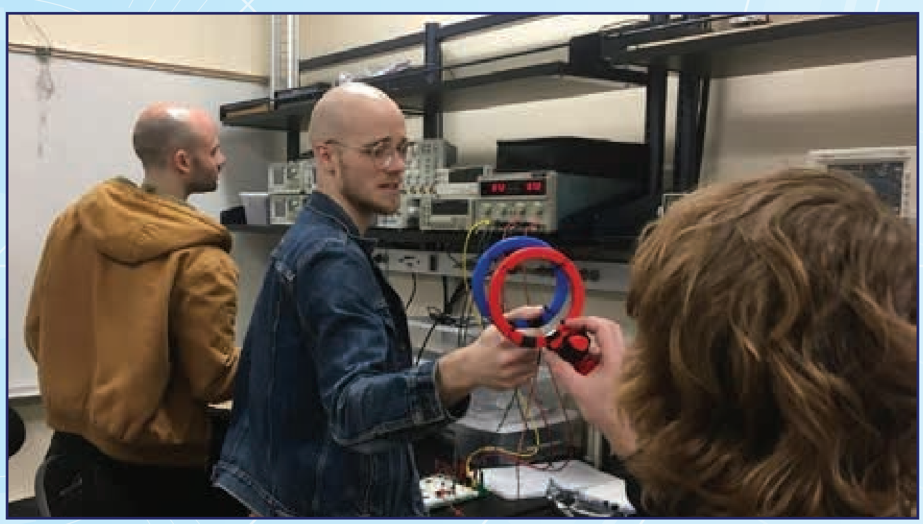
A student conducting Ansys simulation for magnetic field.

Washington State University

Magnetic fields' ability to penetrate lossy mediums, low propagation delay, and relative difficulty of interception of a communication system lead to a very promising communication application based on magnetic induction. The highlight of this mode of communication is the ability to communicate using a transmitter and a receiver in two different mediums, such as water and air. This method of communication will be very useful for the Navy's underwater unmanned vehicles' short distance communication. The goal of this project is (i) to use Ansys, Inc. software to map out the magnetic field strength under different conditions, when the transmitter and the receiver are in the same or different mediums; (ii) to design, implement, and demonstrate proof of concept of a magnetic induction communication system for undersea applications; and (iii) to verify the simulated results.

This project is a continuation of work done by previous WSU - BSEE student groups working on their senior capstone design project. In this phase of investigation, Ansys software has been used successfully in the simulation of a magnetic field at various distances between the transmitter and the receiver and for different orientation of the coils using the Ansys Maxwell software. This simulation allows an alternating current (AC) excitation of a desired amplitude and frequency to be used. The model calculates the magnetic field produced by the AC excitation and models the eddy current effects produced in conductive materials. The magnetic field vectors can be visualized within the computer-aided design (CAD) model, and the magnetic field magnitude is graphed along lines drawn within the simulation space or exported as a table of values. Ansys Simplorer, a circuit simulator, combined with Ansys Maxwell time-varying simulation models, improves the simulations of input/output signal behavior. In our model, it is used with the transient analysis simulation to create the resonant effect caused by the capacitors used in parallel with the transmitter and receiver coils.

In the next phase of this project, transmitter receiver circuits are designed, constructed, and used to validate the results obtained in Ansys simulations. A frequency modulation scheme is used to minimize the contribution of environmental noise.



Testing magnetic induction communication system.

NUWC Newport

Sensing and Computational Methods Enabling Edge Computing for Autonomous Platforms

Professor:
Scott Koziol

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

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

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

Baylor University

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

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

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

NEWPORT, RI - Baylor University students had the unique opportunity to work alongside Naval Undersea Warfare Center Division Newport technical experts Dr. Eugene Chabot (back row, from left) and Dr. John DiCecco as participants in this summer's Naval Research Enterprise Internship Program. The students continued work on a Naval Engineering Education Consortium project to improve the autonomous capabilities of robots.

NUWC Newport

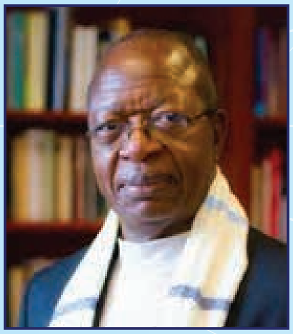
Advanced Mathematical and Computational Methods for Probability Densities Evaluations and Information Measurements Involving AI/Ml

Professor:
Bourama Toni

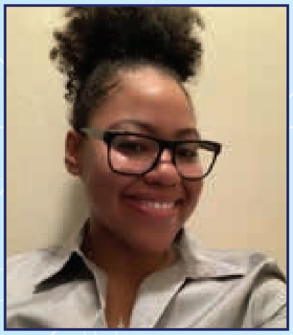
Students:
- PhD: 1

Howard University

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



Dr. Bourama Toni.



NEEC PhD Student.

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

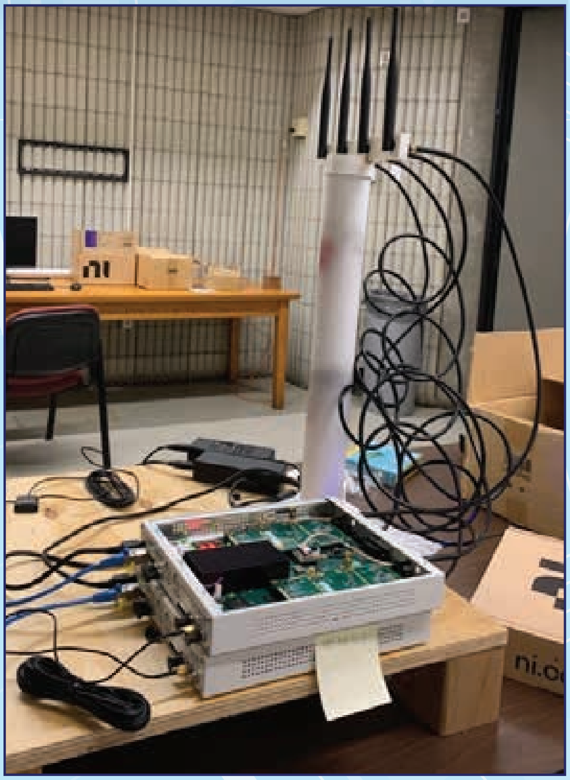
An Adaptive Deep Learning Architecture with FPGA Acceleration for Continuously Monitoring and Characterizing Operations and Promptly Reconfiguring SDR in Spectrum Contested Environments

Professor:
Ruolin Zhou

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

University of Massachusetts Dartmouth

The electromagnetic spectrum (EMS) ranges from radio waves, microwaves, visible light, to X-rays, and supports Department of Defense (DoD) air, land, sea, space, and cyberspace spectrum-dependent wireless systems and applications. Due to the technology evolution as well as 5G and beyond, which provides high capacity, faster speeds, world-wide connectivity, terrestrial and non-terrestrial communications, it has been harder for the warfighters to have freedom of action within the EMS to be successfully operational in congested, contested, and constrained EMS environments globally. The DoD has developed the "2020 Department of Defense Electromagnetic Spectrum Superiority Strategy" to ensure that the US military maintains their ability to operate in the EMS and to retrieve the "freedom of maneuver" in future by dynamically accessing the EMS. A key barrier to advance the "freedom of maneuver" in the EMS is the lack of efficient and effective methods to sense the EMS and learn surrounding operations and signals in dynamic EMS environments. Therefore, the goal of the project is to continuously monitor and characterize operations and signals in dynamically congested, contested, and constrained EMS environments (especially the 3 kHz-300 GHz radio spectrum band for communications and radars) to better meet DoD's command, control, and communication needs on their battlefields and beyond as well as Navy's needs in EMS-dependent applications and systems. In 2022, we implemented a 2-dimensional region proposal-based convolutional neural network (R-CNN) to simultaneously detect and classify multiple RF signals. Meanwhile, the algorithm was accelerated on a field-programmable gate array (FPGA), a low-cost and portable solution. With FPGA acceleration, a tenfold increase in classification speed was achieved while retaining the exact same accuracy when compared to the same neural network running on a mid-range GPU. Then, we transformed the algorithm to take 1-D digitized baseband samples rather than images to reduce the computation complexity. The 1-D faster RCNN (FR-CNN) can detect multiple active signals over an ultra-wideband without preprocessing the signal to obtain scalogram or spectrogram images. Additionally, a software-defined radio-enabled RF environment emulator and antenna array testbed were built for the tasks in the next year.



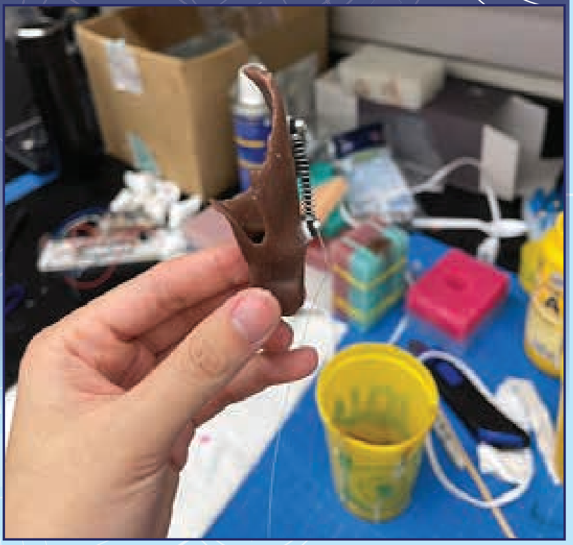
Testbed for angle of arrival estimation using software defined radio.

Students work on software-defined radio-based emulation of RF environments.

Bioinspired Physical Deep Learning Paradigm for Sonar Sensing in Cluttered Environments

Professor:
Rolf Müller

Students:
- **Undergraduate:** 20
- **Master's:** 1
- **PhD:** 1



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

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

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.

The biosonar system of bats is characterized by unique features as well as capabilities that result from a combination of sensory information encoding in the physical domain and signal analysis in the computational domain. The project has laid the groundwork for understanding the interplay between the physical and computational dimensions of bat biosonar by working on soft-robotic reproductions for the peripheral dynamics of bat biosonar and integrating them with signal processing hardware that is capable of deep-learning inference. Using the soft-robotic system developed in this project, our research has demonstrated a number of novel sonar sensing skills that had not been previously realized using conventional sonar hardware. In particular, we have demonstrated highly reliable detection of narrow passageways in foliage despite sonar beams that are much wider than the angle subtended by the respective passageway. Furthermore, we have shown that single, short recordings of biomimetic echoes are sufficient to identify the recording locations on a large scale (10s of km) and have yielded a spatial resolution on a small scale that was commensurate with the resolution of the GPS that was used as a reference. Finally, we have established a novel nonlinear paradigm for determining the direction of a narrowband sound source using just a single receiver by virtue of direction-dependent Doppler shift signatures created by a moving baffle surface.

The main technical objective of the research reported here has been to create a soft-robotic system that is able to recreate a substantial portion of the peripheral dynamics seen in the biosonar system of rhinolophid and hipposiderid bats, i.e., the ability of these animals to deform their noseleaves upon ultrasound emission and their outer ears upon ultrasound reception. The second central objective of the research has been to study the integration of the biomimetic echo emission and reception with deep-learning models of the signal processing that must occur in bats to enable the navigation and hunting skills of the animals. To enable this research, the goal has been to deploy the biomimetic sonar in vegetated natural environments to collect large data sets of "clutter echoes" that can then be analyzed using deep learning techniques.

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.

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

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

Students:
- Master's: 1

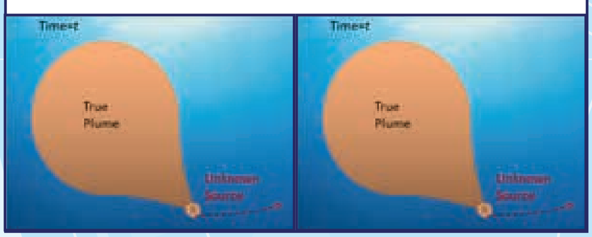
Worcester Polytechnic Institute

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

The project advances the state of the art. The estimation approach is physics-inspired and incorporates the plume dispersion modeled by the 3D advection diffusion equation, the motion of the unknown source modeled as an exosystem, the motion of the guided AUVs modeled by dynamical equations, and the concentration sensor modeled with bandwidth and noise. The estimation approach is data-driven because, through adaptive sampling in the plume, the burden of processing "big data" is replaced by significantly reduced "smart data" taken by the limited number of AUVs. The estimation approach is also machine-learning enabled and provides via a physics-informed scheme the unknown ocean currents, and source strength and location. The estimator is implemented with advanced computational methods bridging the multiple scales of the highly-dynamical system and is real-time executable onboard AUVs.

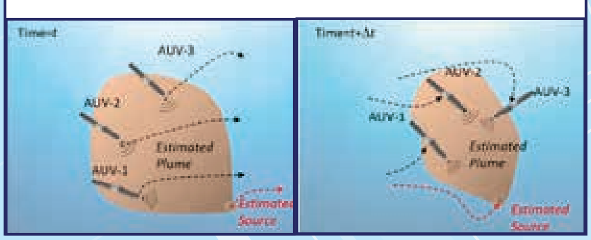
The estimation approach provides human interpreted results in real time, plume concentration, and source tracking that can lead to effective decision making. The project outcomes have impacts on applications of interest to the Navy such as search-and rescue operations and environmental monitoring. The project engages supported graduate and unsupported undergraduate students and contributes to their education for potential future careers in the DoD.

Underwater Moving Source and Resulting Plume



Plume formation from a moving underwater source that releases a trace gas or liquid in the environment.

Underwater Moving Source and Resulting Plume



A network of AUVs estimates in real time the plume concentration, the source location, and its strength.

Students work on software-defined radio-based emulation of RF environments.

Cyber-Physical Security for Undersea Warfare Systems

Professor:
Sandip Roy

Students:
- **Undergraduate:** 11
- **Master's:** 2

Washington State University

Cyber-attacks and failures on undersea platforms, including manned submarines and autonomous underwater vehicles, can cause systemic mission failures and introduce risks to safety-critical physical world systems. This project seeks to catalog cyber threat vectors for undersea platforms and to understand the holistic physical-world impacts of these threats. Through these analyses, the project also aims to support the strategic design of cyber- security tools for preventing access to undersea platforms, as well as monitoring capabilities for detecting and mitigating threats. The project team is focusing on two particular emerging needs: 1) detecting cyber threats to embedded systems from measurements of physical-world side channels like sonar and propulsion functions; and 2) assessing and designing cyber-security for new containerized applications that are being deployed on computer systems in the undersea space.

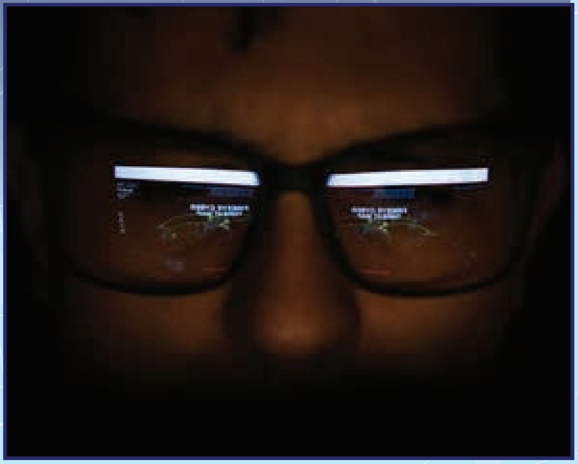
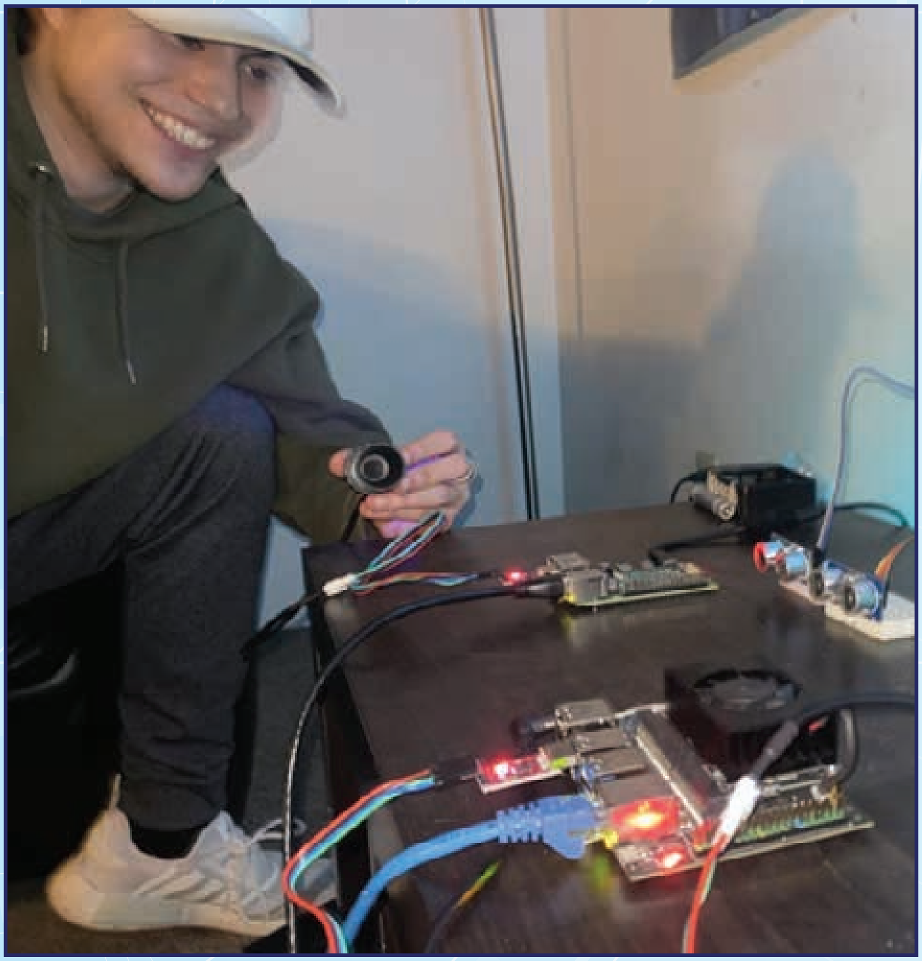


Image courtesy of Defense Visual Information Distribution.

Image courtesy of Defense Visual Information Distribution.



Student working on his senior design project: side-channel sensing of an embedded system with peripherals like a sonar transceiver.

Geomagnetic and Bathymetry Based Navigation System for an UUV

Professor:
Manhar Dhanak,
Pierre-P Beaujean,
Edgar An

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

Florida Atlantic University

In GPS-denied areas, unmanned underwater vehicle (UUV) navigation would typically be based on an onboard inertial navigation system (INS) and a Doppler velocity log (DVL), possibly aided by acoustic positioning from external acoustic transponders. In the absence of acoustic transponders, the vehicle uses INS plus DVL to dead-reckon its path. Navigation inaccuracies in predicted paths arise through environmental disturbances, including currents. If available, acoustic transponders enable the UUV to determine its position relative to a surface ship or buoys and thereby enable making positional corrections. However, the range of the transponders is limited, and, in the absence of GPS, position is available only relative to fixed buoys or a stationary surface ship. An alternative approach is geophysical navigation, involving utilization of environmental features for localization, using sonar, stereo cameras, or magnetic field maps. We have developed algorithms and conducted simulations of geomagnetic and bathymetry-based navigation, assessed the feasibility of implementing a total field magnetometer on a REMUS 100 UUV, and initiated its implementation on the vehicle, in support of conducting field trials using a magnetometer obtained under the previous NEEC effort with Naval Surface Warfare Center, Panama City Division (NSWC PCD). Previous experience by the PIs in UUV-based electro-magnetic field (EMF) surveys and detection and classification of targets on the seabed will be used to assist students in algorithm development, modeling and simulation, system integration, UUV operations, and hands-on testing and technology development. The project will involve 2 MS students, 2 undergraduates and 10 affiliated students supervised by the faculty mentors.

NEEC student performing field experiments with a modified REMUS 100 UUV.

NEEC student showing NSWC PCD NEEC Mentor Harryel Philippeaux modifications to a REMUS 100 UUV during a visit to FAU.

Understanding Deep Learning Architectures with Information Theory

Professor:
Jose Principe

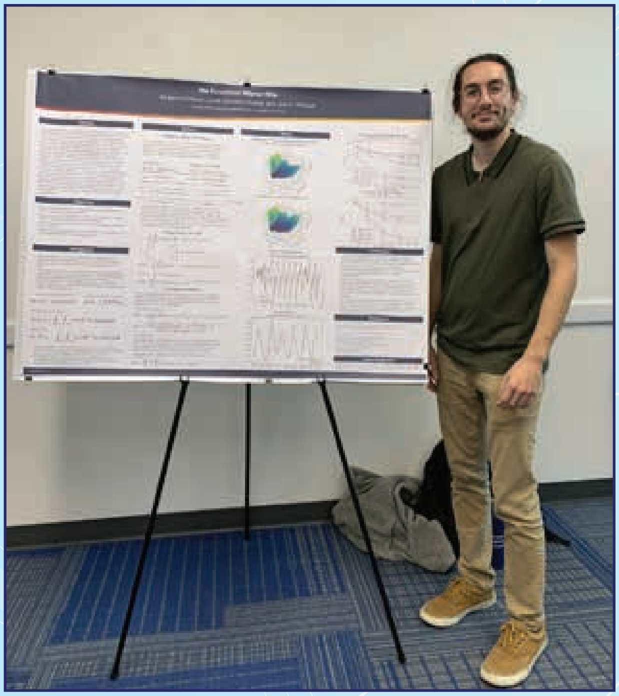
Students:
- PhD: 1

University of Florida

The most current work done under this grant is submitted for review under the title, "The Functional Wiener Filter (FWF)." This work extends the Wiener solution for an optimal nonlinear filter to a reproducing kernel Hilbert space (RKHS) that is nonlinearly related to the input signal. This yields a closed-form solution to an optimal nonlinear filter in a data-dependent universal RKHS.

The FWF embeds the statistics of the signal into the metric of a RKHS allowing for an algorithm that is more computationally efficient than comparable kernel adaptive filtering methods, such as Kernel Least-Mean Squares (KLMS), without sacrificing performance. The functional representation built using most kernel adaptive filtering methods grows linearly with the number of training samples. The use of a data-dependent universal kernel helps solve this issue as it simplifies the functional representation in the RKHS. Another important characteristic of the FWF is that the search space is convex, unlike the search space of neural networks which may be non-convex.

The idea of RKHSs with data-dependent inner products is a general idea with potentially many algorithms stemming from this core idea. The Functional Wiener Filter is just one example of this. These data-dependent universal kernels stem from ideas in statistical signal processing, RKHS theory, and operator theory. The mathematical foundations established in these three fields provide a rich platform that can be used to further our understanding of data-dependent RKHSs and develop new machine learning algorithms. While this idea is widely applicable, the computational efficiency shown in the FWF indicates these algorithms may be particularly useful for low-power machine learning applications.



NEEC student presenting his work on the Functional Wiener Filter at the control and cognition conference.

NSWC Panama City

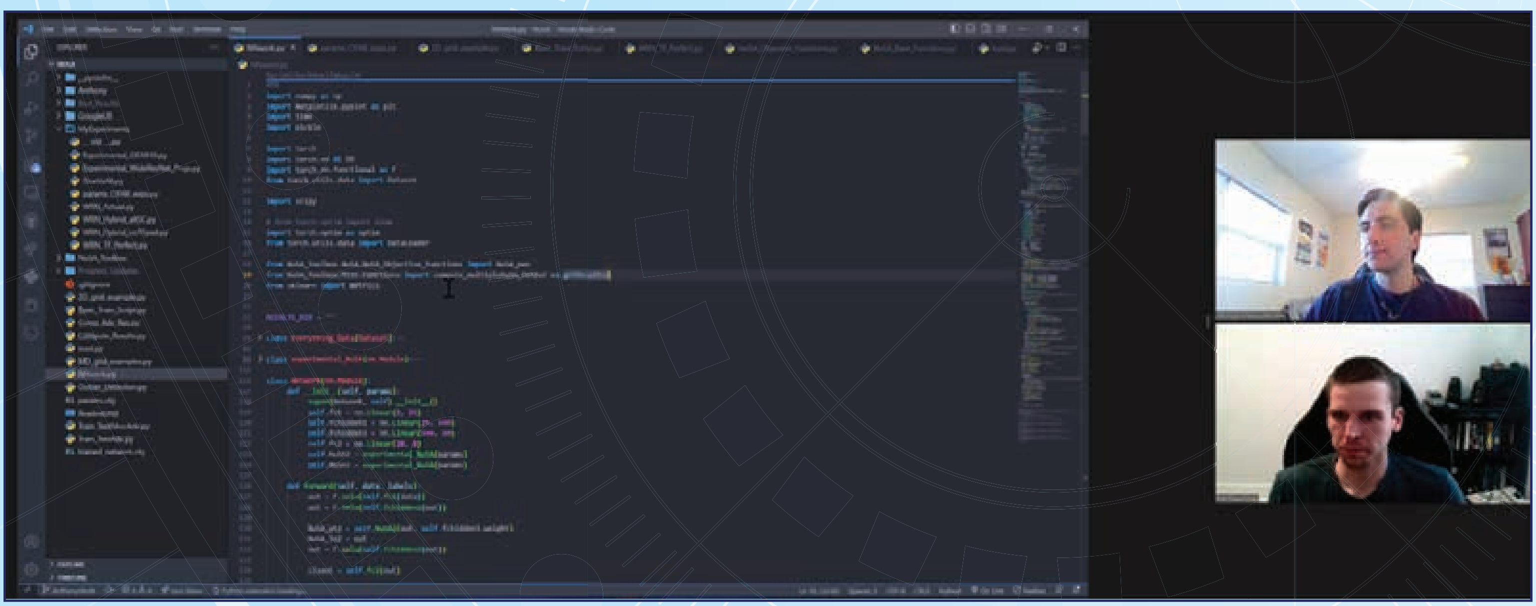
Robust and Reversible Deep Networks

Professor:
Alina Zare,
Paul Gader

Students:
- Undergraduate: 3
- PhD: 2

University of Florida

Neural networks (NN) have become more ubiquitous and achieved state-of-the-art results in many areas but suffer from a lack of robustness. We are improving NN robustness in terms of handling large changes in inputs which produce a small change in the output. We leverage the NN's null space information at each layer to directly integrate an outlier detection method into an NN used for classification.



NEEC student discussing his research with NSWC PCD Mentor Matthew Cook.

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

Professor:
Ananya Sen Gupta

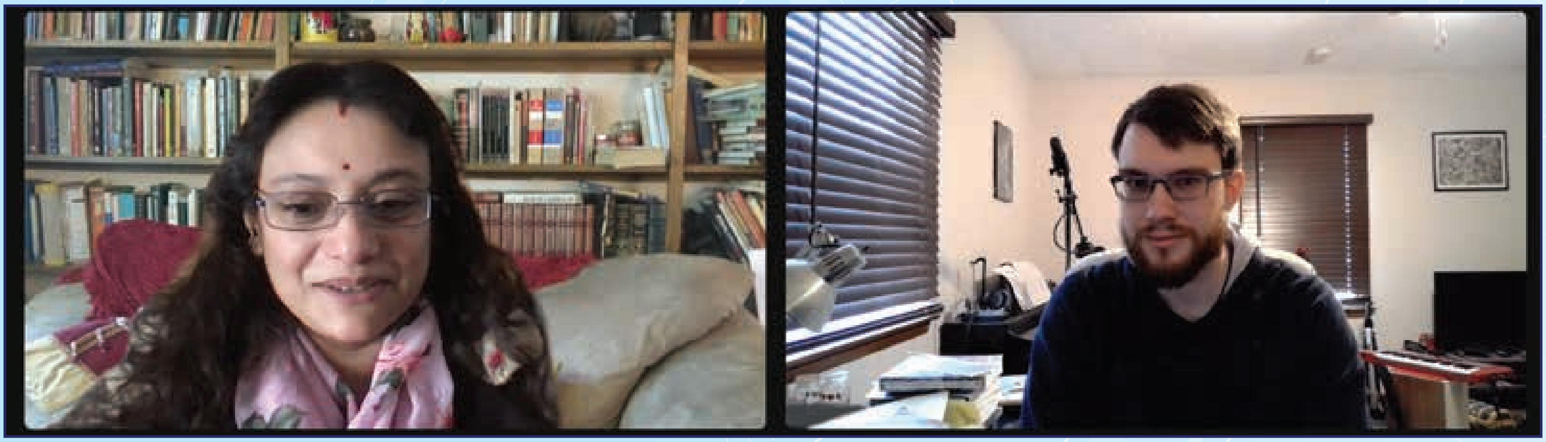
Students:
- PhD: 2

University of Iowa

The broad objective of this project is to develop a robust physics-cognizant mathematical framework for sensing the marine environment in battlespace scenarios. We will study and develop interfaces between the feature dictionaries and popular machine learning techniques with the aim of detection, representation, simulation, and classification of acoustic signals of naval interest. As appropriate, we develop supervised and semi-supervised machine learning techniques that allow "opening the black box" for domain interpretation and incorporation of domain constraints (e.g., number of elastic wave orbits in sonar targets, or the water-sediment interface in buried acoustic sensors). Specifically this project has two independent thrusts related to naval sensing of the oceanic environment using acoustic signals:

(i) Automatic target detection of small elastic targets using domain-interpretable features: We will develop feature extraction and machine learning algorithms that can autonomously differentiate between different classes of acoustic reflections from small-size underwater sonar targets with complex spectral profiles. We distinguish automatic target recognition in this thrust to be very different in scope and aims from other contemporary forms of target recognition. One graduate student has been recruited to perform and develop this research thrust into a thesis.

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



NEEC Professor Ananya Sen Gupta and NEEC student discussing research.

NSWC Panama City

Algorithm Development for Ultrasonic Sensing System for Naval Mine Detection

Professor:
Jason Mitchell,
Brett Byram,
Jack Noble

Students:
- Undergraduate: 8
- PhD: 2

Vanderbilt University

VANDERBILT UNIVERSITY

This project has two distinct parts.

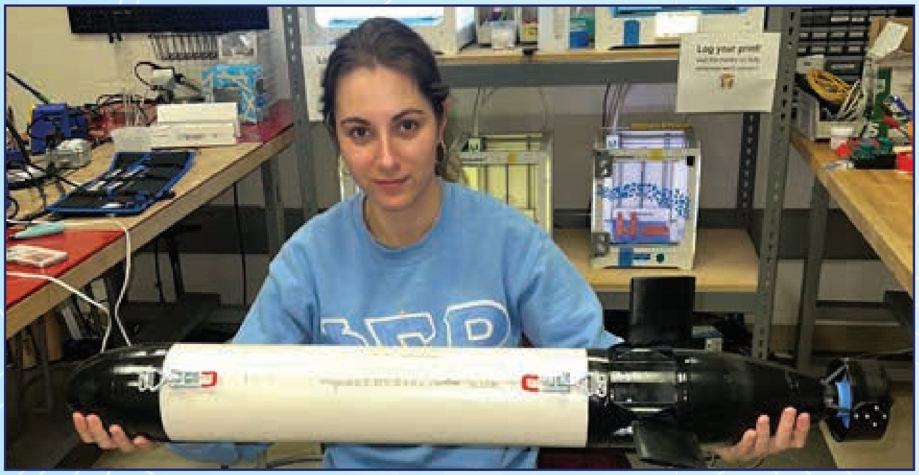
1) A team of graduate students and faculty will develop deep learning algorithms to quickly analyze ultrasound data in murky underwater environments and use this data to control manipulators autonomously performing simple diffusing tasks. These developments will advance the ability of unmanned underwater vehicles to detect and autonomously manipulate underwater objects and to autonomously charge and send communications.

2) A team of undergraduate students working in a senior design capstone course. Vanderbilt Underwater Vehicles (VUV) is working with the Naval Surface Warfare Center (NSWC) Panama City Division to develop autonomous underwater swarming vehicles. These unmanned underwater vehicles (UUVs) have roles in mapping underwater terrain and objects. Such missions are currently fulfilled by large vehicles that require two operators to deploy. This vehicle's price is not disclosed, but commercial UUVs produced by Blue Robotics that lack tactical capabilities cost around $4,000. Because of the high-risk nature and increasing demand for underwater missions, it is beneficial for them to be rapidly deployable and easily replaceable. Thus, Vanderbilt Underwater Vehicles is focusing project efforts on developing low-cost, easily transportable, and easily manufactured UUVs. The team is addressing these challenges by leveraging rapid prototyping technology, testing inexpensive means of waterproofing, and designing unique magnetic couplings.

NEEC student weighs a prototype low-cost swarming UUV as part of a NEEC-funded senior capstone project.

NEEC students holding prototype of a low-cost UUV with magnetically attached fins.

NEEC student testing a magnetically attached fin.



NEEC student holding a prototype UUV as part of the NEEC-funded senior capstone project.

NSWC Panama City

Seafloor Characterization from Free Fall Penetrometers Using Machine Learning

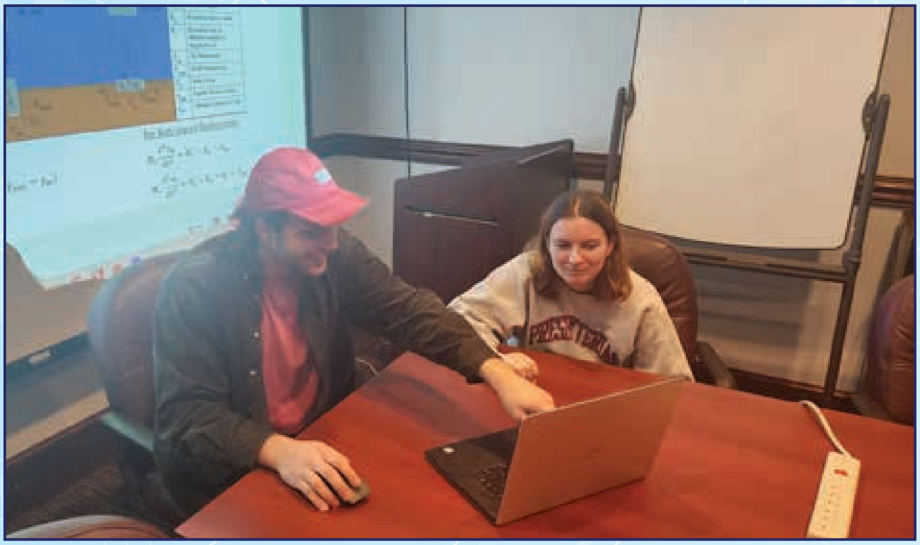
Professor:
Nina Stark,
Alba Yerro Colom,
Adrian Rodriguez-Marek,
Anuj Karpatne

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

Virginia Polytechnic Institute and State University

Rapid seafloor surface sediment characterization is important for many naval applications, including navigation in areas of active sediment dynamics, sensor burial prediction, sensor placements, unexploded ordnance detection and classification, to name just a few. Free fall penetrometers (FFP) offer a means for rapid seafloor sediment characterization from any vessel of opportunity and in a wide range of environmental conditions. FFP seabed profiling has been found to be reliable and accurate, and methods are available to derive seabed stratification, including layer thicknesses, to classify sediment type, and to estimate geotechnical properties, such as undrained shear strength, friction angles, and relative density. However, those data analysis methods can be complex and currently require expert users. The proposed work focuses on using a large existing FFP deployment and sediment information database to develop a machine learning model to facilitate FFP data analysis with high accuracy but without need for expert users. The research tasks include: 1) the preparation of the database, 2) expansion of a current numerical model simulating FFP deployments for sensitivity analysis and investigation of physical processes leading to the seabed specific FFP profiles, 3) development of a machine learning model for FFP data analysis, and 4) assessment of the accuracy of FFP results in comparison with seabed coring. Integration of students into naval research is a core objective of this proposal. At least two graduate students and two undergraduate students will be actively involved in the research. The team includes leading experts in FFP development and data analysis, numerical simulations and probabilistic analysis in geotechnical engineering, and physics-informed machine learning. The proposed work is expected to pave the way for more user-friendly, reliable, and accurate data analysis of FFP deployments in the framework of rapid seabed surface investigation for naval applications, and to introduce our students to naval research.

NEEC students testing a free-fall penetrometer during field tests.



NEEC student with another graduate student discussing modeling & simulation results.

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

Professor:
Vikas Tomar

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

Purdue University Northwest

Our project aims to answer several questions. How can a Battery Management System (BMS) interface with various commercial battery packs, usually with their own BMS, and how can the interface be used to improve and predict long-term performance and safety? How can machine learning models based on performance history data be used to improve an agnostic BMS? Can this system be actively tested on a live and relevant system? This aim aligns with the original objective where we wanted the BMS to wire agnostically to any commercial battery pack initially and then scale to higher voltages, including 12 V DC, later.

We've designed a system useful for as many batteries, battery packs, and BMSs as possible. The main power of the system is the ability to improve performance and safety by actively utilizing machine-learning and physics-based models to predict future values of battery health characteristics like state of change (SOC) and remaining useful life (RUL). It does this by sending data back to a main CPU or server, and this data is used in both advanced BMS control and advanced prediction of battery health indicators.

This system has applications for a wide variety of UAV, UUV, and other battery-powered systems in the naval ecosystem. Battery storage, use, and replacement are all key areas that depend on battery health. This battery health is often a black box of knowledge, where the entire life of the cell is not readily available. Our system predicts, using advanced ML modeling and physics-based correction, how long a battery or battery pack will be useful given only its current in-operation data inputs.

Laboratory research on Battery Management Systems (BMS).

NSWC Philadelphia

Unifying and Securing Naval SCADA Networks through Scalable SDN

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

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

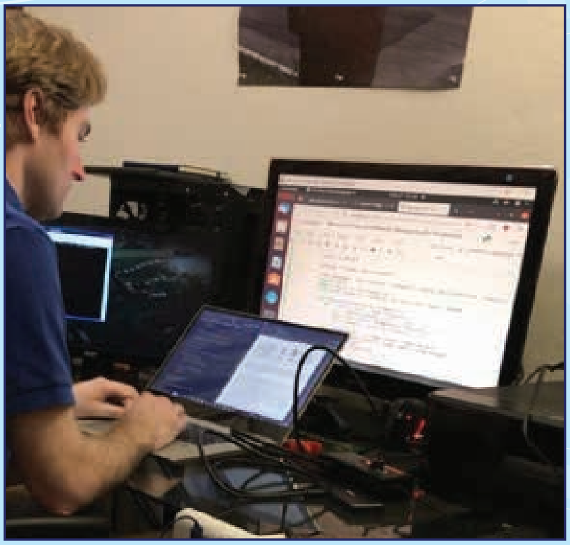
Temple University and The Pennsylvania State University

This project aims at designing and utilizing novel, open, and scalable software-defined networking (SDN) techniques to enhance the resiliency/survivability, scalability/compatibility, and security of naval supervisory control and data acquisition (SCADA) networks. The proposed SDN architecture for naval SCADA networks consists of three parallel planes: data, control, and application, which are designed separately but collectively work together. SDN controllers communicate with the application plane through northbound application programming interfaces (APIs), receive instructions from the application plane, and relay them to corresponding network components. Open-source protocols (e.g., OpenFlow), network 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.

Pennsylvania State University student.



Pennsylvania State University student.

Temple University students.

Validating and Advancing Fastener Design for Tensile Loads

Professor:
Mark Denavit

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

University of Tennessee, Knoxville

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

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

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

Undergraduate student performing harness testing on bolt sample.

Master's student preparing a bolt tension test.

NSWC Port Hueneme

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

Professor:
Tobias Höllerer

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

Student at ANTX poster session.

UCSB Media Arts and Technology Open House presentations on our mobile augmented reality and computer vision projects.

University of California, Santa Barbara

Effective surface ship maintenance is a significant challenge for the US 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 contributed basic research toward 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) 3D Scene Modeling from AR camera feeds via novel deep learning architectures; 2) User Modeling and Understanding; and 3) Mobile AR User Interface Studies (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, the premier international conference on computer vision.

Undergraduate project team presenting their paper at the WACV 2023 Workshop on Pretraining Large Vision and Multimodal Models.

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

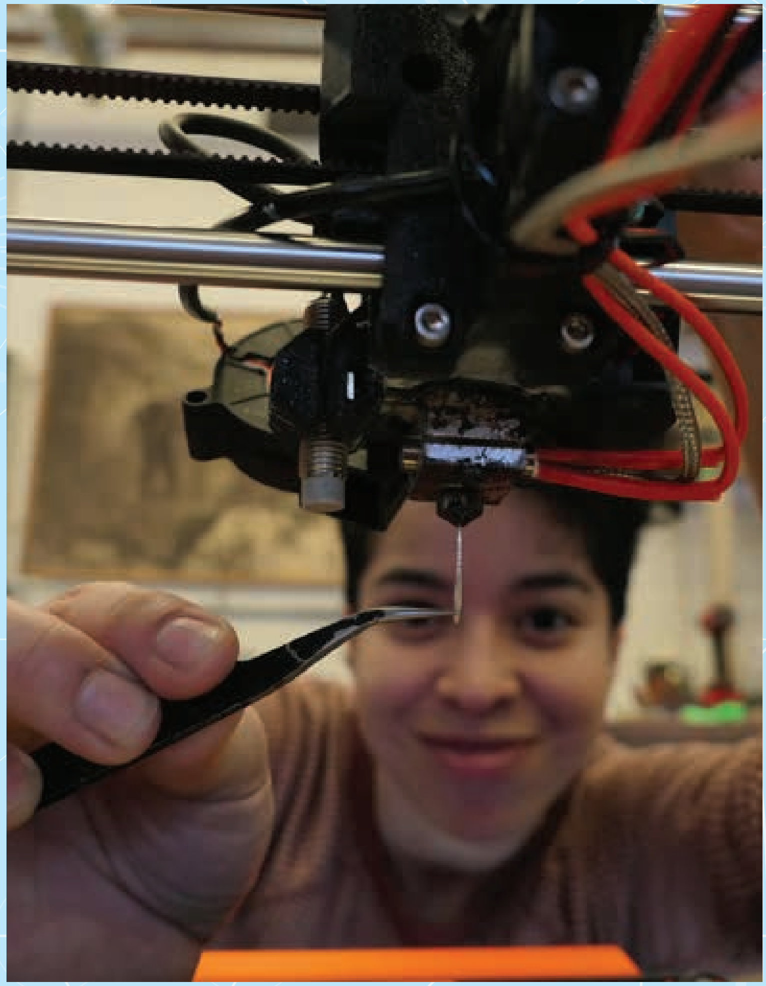
Professor:
Samantha (Sam) Daly

Students:
- Undergraduate: 2
- PhD: 1

University of California, Santa Barbara

As part of the Navy's efforts to advance fleet readiness through sustainable and scalable additive manufacturing (AM), we are investigating how material processing affects mechanical response in AM ferrous alloys, with focus on as-printed strength and part lifetimes. Ferrous alloys are essential components of on-ship infrastructure and materiel, but they require regular replacement and maintenance, which is logistically costly. For the Navy, AM serves as a logistical accelerator, enabling the on-ship printing of serviceable parts based on operating need. However, to effectively utilize the on-ship and flexible design capabilities of AM, it is critical to understand how the strength and lifetimes of AM parts depend on input AM print parameters and how the resulting mechanical properties of the manufactured parts will differ from existing technically certified systems. To explore the strength of ferrous AM components, localized damage nucleation and progression in AM printed specimens will be measured at the micro-scale in real time under load, using an approach known as scanning electron microscope digital image correlation (SEM DIC). With SEM DIC, specimen failure can be correlated directly to specific microscale structures of the printed parts that result from AM processing choices, which can be used as a basis of comparison to current technically certified forged and machined parts. Overall, this project will result in information on AM part capabilities that will strengthen and expand the Navy's industrial base to achieve strategic defense objectives.

University of California, Santa Barbara.

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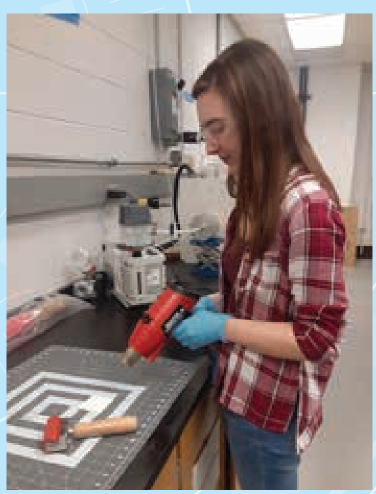

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