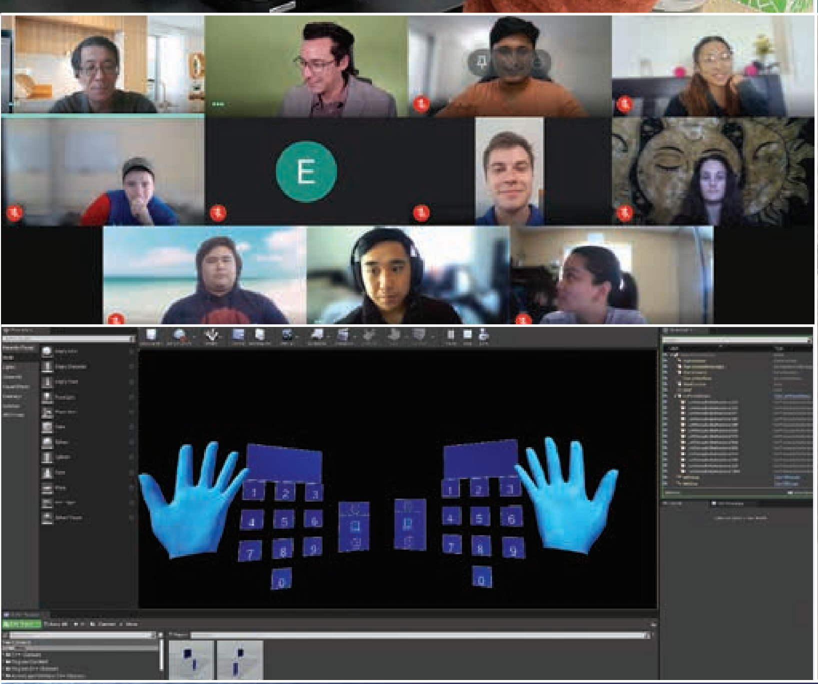
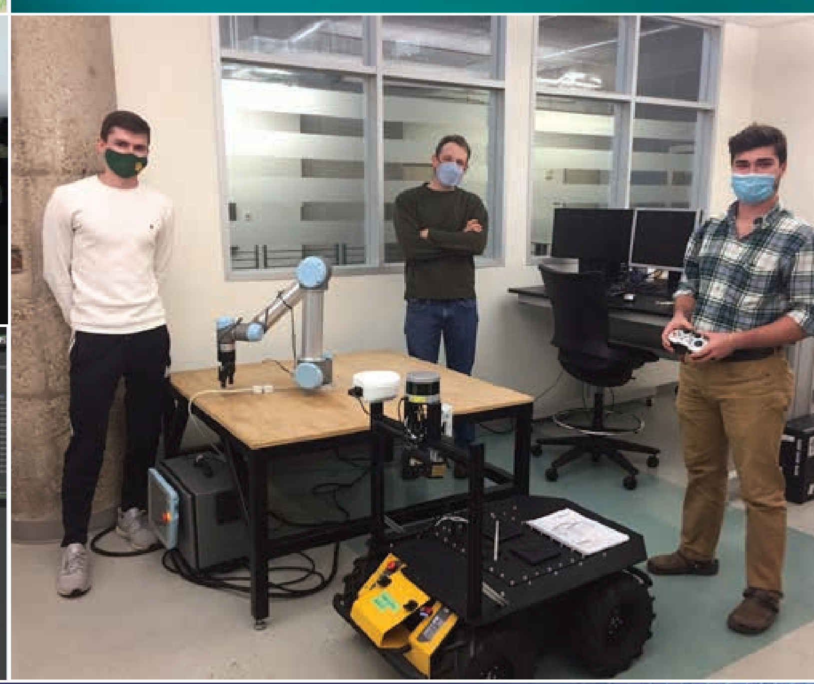
NAVAL ENGINEERING EDUCATION CONSORTIUM PROCEEDINGS

2021

NEEC

Naval Engineering Education Consortium





NAVSEA WARFARE CENTERS

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Message from the Executive Director

Welcome to the fourth annual Proceedings of the Naval Engineering Education Consortium (NEEC). This NEEC Proceedings highlights our 2020 NEEC activities by describing and documenting current research projects that were conducted under unique conditions. Like other institutions, colleges and universities across the nation were significantly affected by the COVID 19 pandemic. Nearly every aspect of college life was altered, with most institutions canceling in-person classes and moving to online-only instruction. As a result, colleges and universities with NEEC grants were required to be more flexible and more creative to continue the valuable research performed as part of these NEEC projects.

That dedication was essential because NAVSEA's NEEC program is critically important for the hiring, development, and sustainment of the technical knowledge base that underpins our undersea and surface warfare missions. Those missions remain critical to the Navy and the nation as we execute our strategic vision of "Enabling maritime superiority for today's Navy, tomorrow's Navy, and the Navy after next."

The NAVSEA Warfare Centers are committed to expanding and enhancing relationships with our partners in industry and academia. That's why we are so proud that the NEEC program has awarded more than 50 grants to U.S. universities through all 10 NAVSEA Warfare Center Divisions. Whether it is developing autonomous navigation systems for undersea vehicles in the warm waters of the Gulf of Mexico or evaluating under-ice acoustics at the Great Lakes Research Center, cutting-edge technologies are being addressed today at NEEC universities and colleges. As we look for sources of inspiration to develop the products and services for tomorrow's Navy—as well as talented and knowledgeable students to lead our future workforce, there are no better partners than America's exceptional colleges and universities.

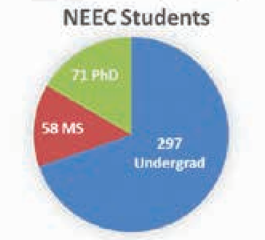
As you'll see, this NEEC Proceedings represents a monumental team effort. I would like to recognize the people that make the NEEC program so successful: the professors and students, the dedicated scientists and engineers, the mentors, government grants officers, and the NEEC directors at the NAVSEA Warfare Centers. To all of you, thank you and congratulations on a job well done.

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

About NEEC

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

2020 was a challenging year: "the academic world was significantly disrupted by the spread of the coronavirus as more than 1,300 colleges and universities in all 50 states canceled in-person classes or shifted to online-only instruction." According to the National Conference of State Legislatures (NCSL), "many campuses developed plans to merge in-person instruction (with social distancing) and online learning, with varying degrees of success by institution.



The NEEC colleges and universities then had to adapt to the various models, as can be seen in the following project write-ups, such as on-line instruction and learning. Mask wearing and social distancing became the norm. (Please note that some pictures were taken earlier in the year before the mask requirements). Over 50 U.S. universities, with well over 400 science and engineering students, participated in the program, as shown in the chart.

These NEEC students were still able to engage in project-based research that targets the Navy's technology needs. The objectives of NEEC are to:

- Acquire academic research results to resolve the Navy's technological challenges.
- Hire talented students graduating with naval engineering research and development experience.
- Develop and maintain exceptional working relationships with naval engineering universities and professors.

As we move forward, in what we hope will be a post-COVID world, the NEEC team is continuing to look forward to many years of productive research, extended relationships with academia, and students who will transition to Navy civilian service jobs as new professionals and develop into future technology leaders for the nation.

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

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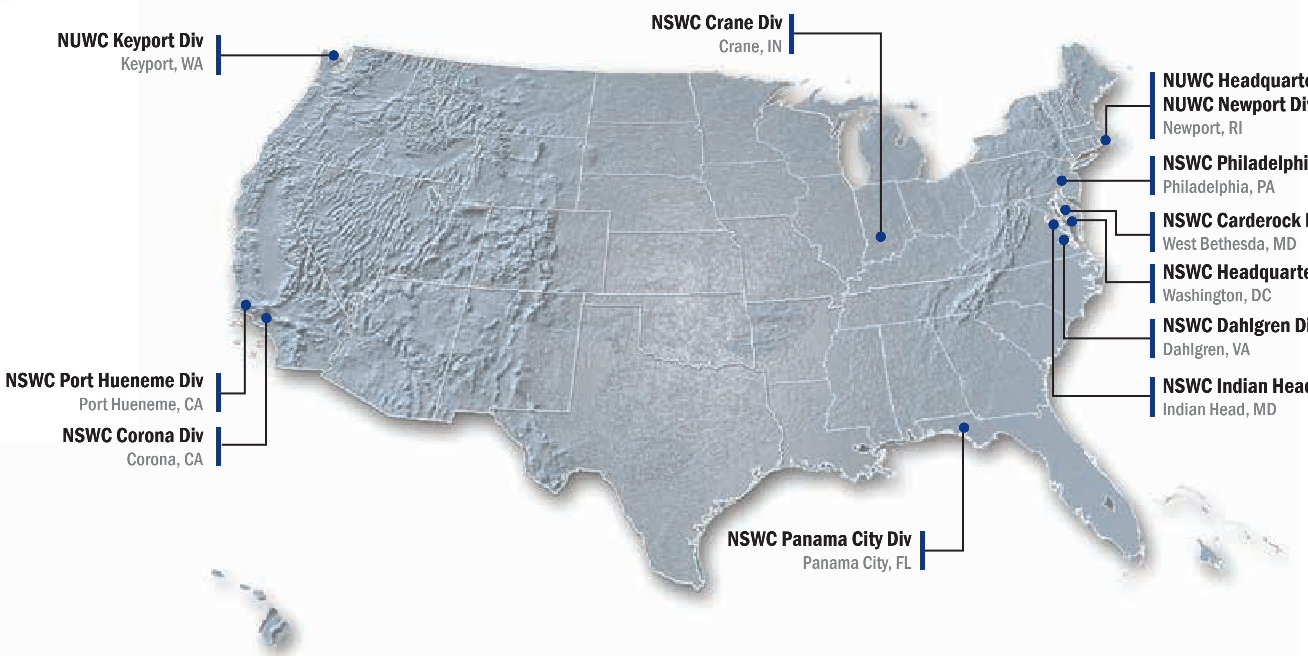
About the Warfare Centers at the Naval Sea Systems Command (NAVSEA)

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

The Consortium

- Warfare Center partners



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

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

NSWC Carderock

Robust Multi-Domain Situational Awareness Through Sensor Fusion

Professor:
Dr. Eric Coyle

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

Embry-Riddle Aeronautical University

EMBRY-RIDDLE
Aeronautical University
DAYTONA BEACH, FLORIDA

One of the key challenges to widespread integration of unmanned assets in Navy missions is the inability of the systems to coordinate efforts as effectively as manned systems. There are a variety of Navy missions that could benefit from the coordinated efforts of aerial, surface, and underwater unmanned systems to perceive the environment. As a result, this research investigates methods of representing, fusing, and processing perception data collected from underwater, surface, and aerial unmanned assets.

The research team has developed and is currently testing a method of detecting and classifying maritime objects based on point cloud representations, grid-based clustering, and concave hull analysis. This method has been tested both offline and online using USV collected Lidar data and proven highly effective. The research team is also currently testing the efficacy of this method on UUV-collected sonar data and UAS-collected Lidar data. A novel mapping system has been developed based on computational geometry that enables fusing object detections from each sensing modality into a single map of the environment that maintains object geometries and classification information for unmanned system situational awareness. All techniques used by the research team are intentionally designed to run in real time on the unmanned systems rather than offline in post-processing.

ERAU Faculty and Students Monitoring Unmanned Systems During Testing at Daytona Beach, FL.

ERAU Students Preparing the UUV.

NSWC Carderock

Senior Design Project in Support of Naval Applications

Professor:
Pierre-Philippe Beaujean

Students:
- Undergraduate: 21

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 6-7 undergraduate students that are supported by faculty and technical staff. Projects sponsored by the NEEC program include:

- An Autonomous Underwater Landing Vehicle for Current Monitoring that can be deployed/recovered from a small research vessel, record ADCP data, and then return to the surface for retrieval.
- A Self-Docking and Self-Anchoring Autonomous Surface Vessel, which can autonomously release from a docking station, travel to a remote location, anchor, and then return to the docking station.

Both projects aim to engage students with hands-on experience and promote both student interest and understanding of marine platforms, autonomy science, and naval technology.

Top: Fabrication; middle: Team of the Self-Docking and Self-Anchoring Autonomous Surface Vessel; bottom, from left to right: Pool Testing and Design.

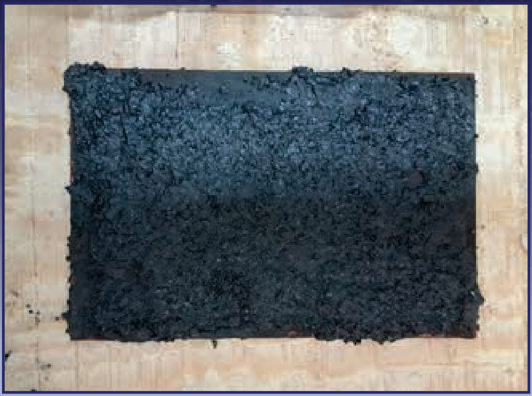
Left: Pool Testing; right top: Pool Testing and Team of the Autonomous Underwater Landing Vehicle for Current Monitoring; right bottom: Design.

NSWC Carderock

The Development of Novel Next Generation Cure-On-Demand Ultra-High Solid Non-Skid Coatings

Professor:
John A. Pojman

Students:
- PhD: 1



Non-skid coating.

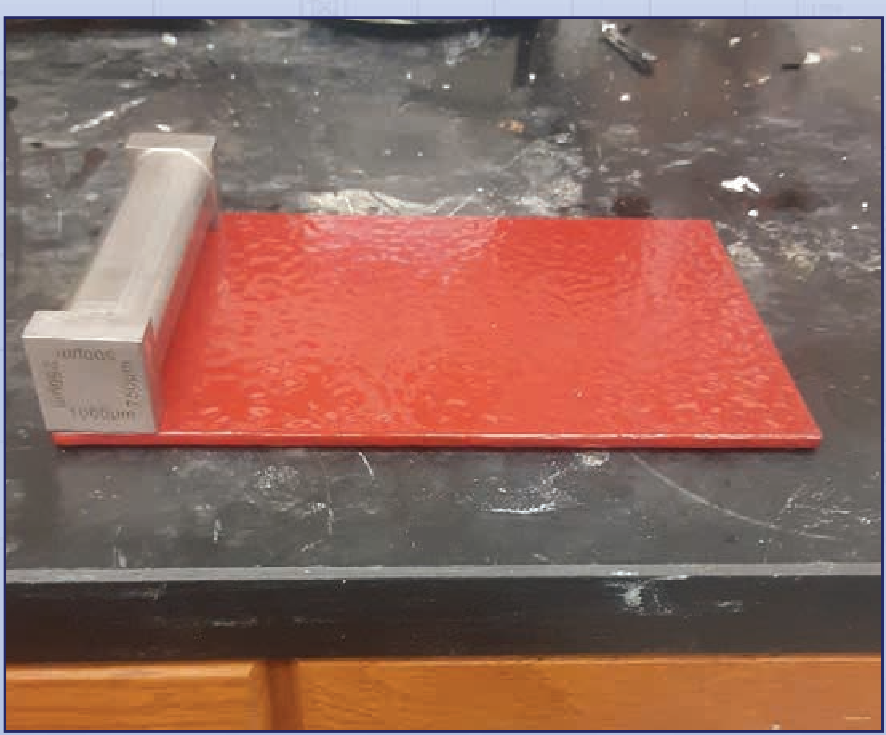
Drawdown bar on substrate. The drawdown bar is used to control the coating thickness.

Louisiana State University

The goal of this project is to develop a one-pot formulation that can be applied to form an on-demand non-skid coating for Navy ships. The formulations will have shelf lives of months to years and will not require mixing before application. The cure-on-demand aspect is that the formulation will be able to react quickly when heated with an infrared heater so that a coating will be formed within minutes. Also, the formulation contains no solvent and will have low volatile organic compound (VOC) emissions. This technology can help the Navy make coatings in less time as well as reduce VOCs. In addition to being an ultra-high solids cure on-demand system, this coating will offer corrosion protection.

Preliminary results have been promising. We have successfully developed a non-skid formulation that can cure in less than 10 minutes while adhering to a steel plate coated with an epoxy primer. (The steel plates were provided by Naval Surface Warfare Center Carderock Division.) The formulation was developed by testing each parameter of the formula including the resin content, addition of fillers, and coating thickness. The coatings were applied using drawdown bars to maintain a constant thickness. The non-skid formulations were applied using a paintbrush. The combination of large non-skid filler with the paintbrush technique generated the peaks and valleys shown in the coating.

Testing and optimization of the formulation is the next step in the project. Impact testing, water resistance, and chemical resistance will be tested to ensure that the coating meets the required specifications.



Experimental setup. An infrared heater hangs 10 cm above the steel substrate (10 cm x 15 cm).

NSWC Carderock

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

Professor:
Dr. Jose Garcia-Bravo,
Dr. Tyler Tallman,
Dr. Brittany Newell

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

Doctoral student and undergraduate student processing conductive particles and PLA for the creation of 3D-printed sensors.

Purdue University

Multifunctional additive manufacturing (AM) has immense potential to create application- and structure-specific embedded sensors or actuators for structural health monitoring (SHM) of potentially high-risk and high-value assets such as marine vessels, aircraft, and many other critical applications. The focus of this project is the production of materials and processes for the creation of sensors and actuators using fused deposition modeling (FDM) AM. This will allow the production of cost effective, in-house, and custom-made devices for SHM. With this in mind, our goals are to (1) identify methodologies to produce electrically and magnetically capable materials compatible with existing commercial 3D printers, (2) design and create devices that can be used as sensors and actuators for health and condition monitoring, and (3) validate the performance of these 3D-printed devices for sensing applications by benchmarking their performance against commercially available sensors.

Thus far, the Purdue team has been able to use a design of experiments (DOE) approach to experimentally identify optimal production conditions for the creation of a conductive filament used to print piezoresistive-based strain sensors. The process developed by the Purdue team produces a carbon nanofiber (CNF)-modified polymeric filament that is ready to be used in conventional FDM printers for manufacturing 3D-printed sensors.

The Purdue team also has time for fun with 3D printers. In November of 2019 a group of students competed in teams to develop 3D-printed compressed air engines. This event was temporarily postponed in 2020 due to the ongoing pandemic but will return with exciting new 3D-printing-based contests designed to challenge the Purdue undergraduate population.

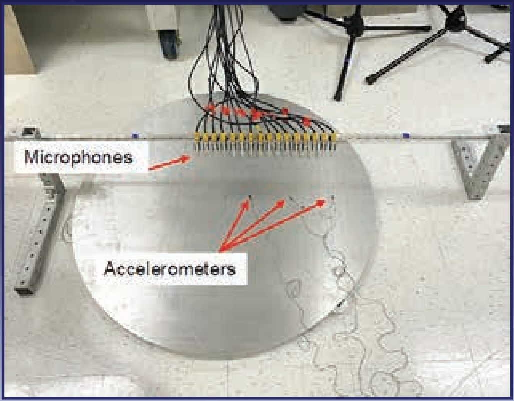
Participating 3D Printing challenge students, Dr. Brittany Newell, and, in the second row, Dr. Tyler Tallman, Dr. Cindy Waters, and Dr. Jose Garcia. The competition encouraged students in Engineering Technology and Aerospace Engineering to explore the design and construction of compressed air engines.

NSWC Carderock

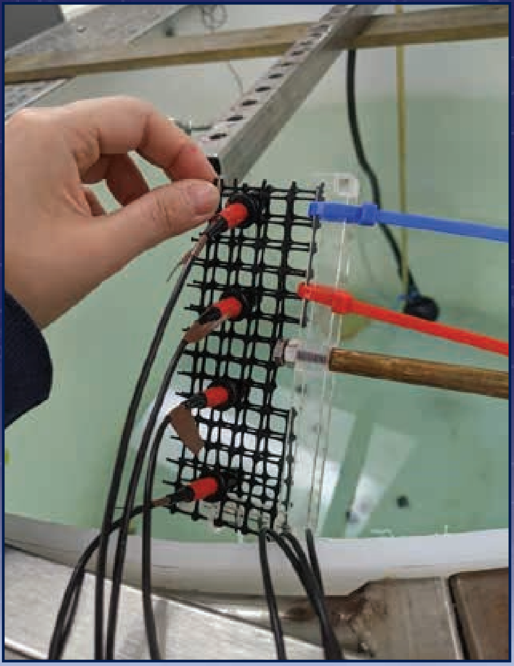
Acoustic Testing and Signal Analysis for Noisy and Complicated Environments

Professor:
Dr. David R. Dowling

Students:
- **Undergraduate:** 8
- **Master's:** 1
- **PhD:** 2



A setup for combined vibration and radiated sound measurements from an impact at the center of an aluminum plate.

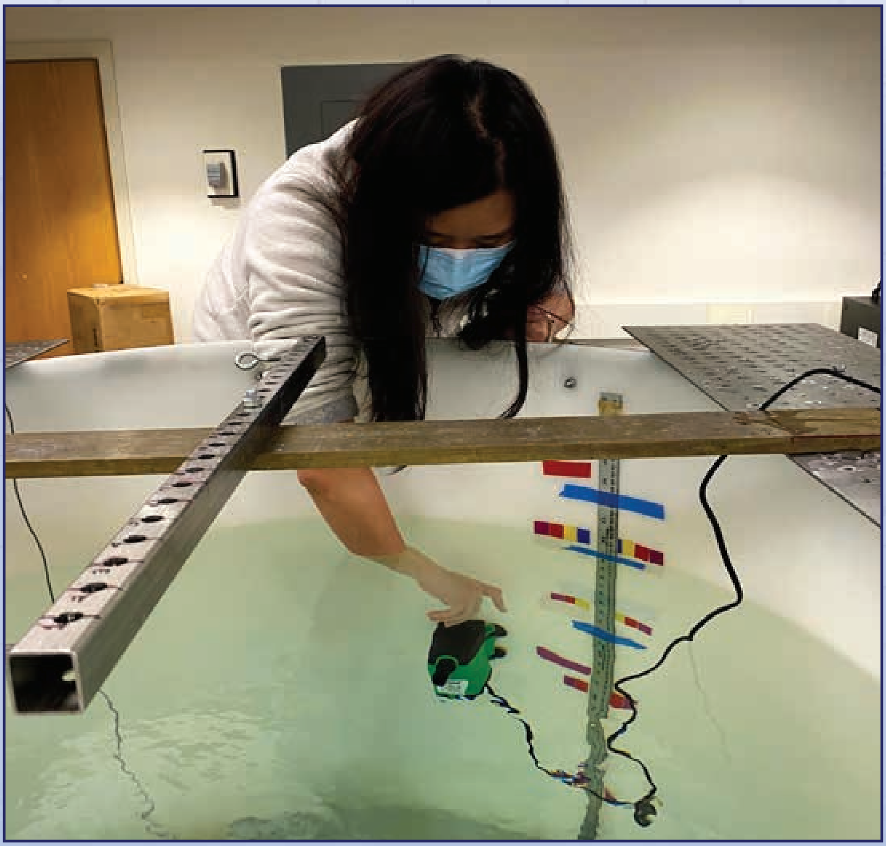


A portion of the NEEC laboratory showing electronic and computer equipment on the left and two of the aluminum plates used for vibration experiments (center and right).

University of Michigan

Acoustic signature reduction and improved means for determining remote sound source characteristics are enduring priorities for the U.S. Navy. Both of these priorities motivate research into new and better ways to analyze and process array-recorded acoustic time series collected in test facilities and on test ranges. 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 from Navy-relevant objects and structures, while emphasizing the training of undergraduate and graduate students.

This project has four tasks. (1) Utilize turbulence-induced noise and vibration data measured in the NSWCCD Anechoic Flow Facility to test modern sound source characterization algorithms and signal processing schemes for noisy environments. (2) Design and conduct axisymmetric transient-impact experiments that include measurements of air- and water-borne sound radiated from a structure that is fluid-loaded by water on one side. (3) Develop and test hydroacoustic measurement techniques for surface pressure fluctuations and wall shear stress caused by wall-bounded turbulent flows. (4) Localize vibration sources on or within a structure using measured time series from an array of accelerometers.



Bubbles that form underwater can ruin acoustic experiments. This picture shows a NEEC student adjusting the water pump used to circulate water in one of the two tanks in the NEEC laboratory in order to remove dissolved gasses.

NSWC Carderock

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

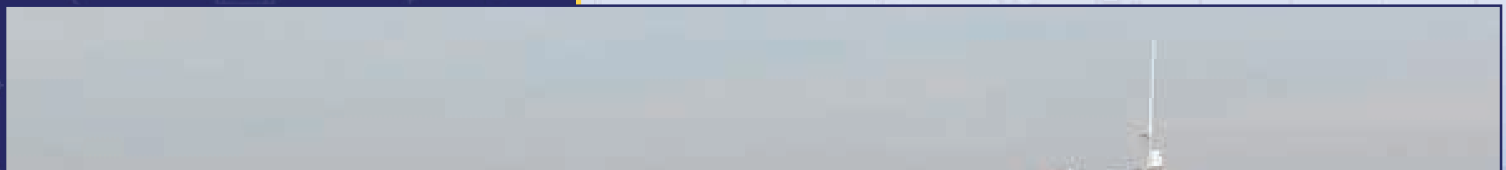
Professor:
Stephen Licht

Students:
- Undergraduate: 2
- PhD: 1

University of Rhode Island

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

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



Researching near-surface operations will be important for Navy vessels.

NSWC Carderock

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

Professor:
Dr. Stephanie TerMaath

Students:
- Undergraduate: 16

Undergraduate researcher printing test specimens to determine the variability in material properties of parts manufactured using Fused Filament Fabrication.

University of Tennessee, Knoxville

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

Student Projects:
Design of an Optimized 3D-Printed Ship Part Using Composite Laminate Theory (CLT). The objectives of this project are to (1) demonstrate the applicability of CLT for 3D-printed parts and (2) use CLT to optimize the mechanical properties of a part. These objectives will be met by 3D printing and testing specimens of varying orientations under tensile load on an MTS machine to determine the applicability of CLT in predicting the mechanical properties.

Water Bottle Recycling Using a 3D Printer. The goal of this project is to design and demonstrate the direct 3D printing of water bottles. The production of such a filament for 3D printing has been demonstrated using shredded water bottles. However, additional research will be conducted to improve strength and fracture properties. Students will modify a 3D Printer to extrude the shredded water bottle material directly—eliminating the step of producing the filament.

Design of an Optimized 3D-Printed Ship Part Using Bimaterial Deposition. Students will apply structural design principles and finite element analysis to design and fabricate a Navy ship part, using a 3D printer with a dual extruder. The part will be tested to better understand printer settings required to achieve appropriate bond strength between the two materials.

Undergraduate researcher designing and printing bimaterial test specimens.

NSWC Corona

High-Performance Post-Quantum Cryptography

Professor:
Dr. Reza Azarderakhsh,
Associate Professor

Students:
- **PhD:** 2

Florida Atlantic University

With the presence of quantum computers, our security protocols based on hard mathematical problems will be insecure and broken. We need to take action to make them secure against the attack of quantum computers. All current communications of DoD/Navy are secured based on classical cryptography, and they need to be upgraded to quantum-safe right now to be safe in the future. Agility is very important as migration takes time and adversaries can download encrypted and classified data now and break them later when they get access to the quantum computers. The main concern is that we do not know when and how we will get access to a large-scale quantum computer, so we need to have our plan ready and start the migration as soon as possible. In this project, we develop quantum-safe cryptography to embed in devices that are used in several communications devices for the Navy. The project will provide performance and timing results to make sure they can be deployed and integrated in the current systems with minimal overhead.

NEEC student analyzing software.

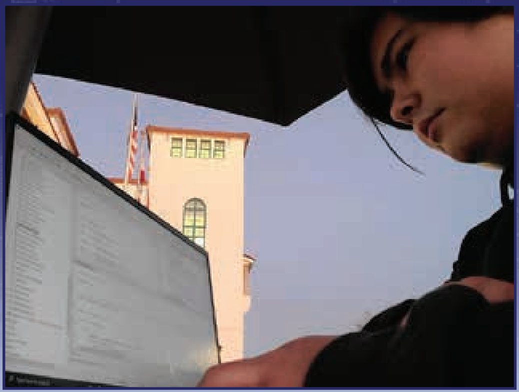
FAU NEEC student analyzing software.

NSWC Corona

Predictive Maintenance of Naval Equipment Using Text Mining

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

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



While enjoying the weather, a NEEC student develops software.

San Diego State University

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

The interdisciplinary SDSU research team is dedicated to tackling this problem by searching for key words and phrases used frequently in maintenance logs before equipment failures. The team is developing algorithms to detect "smoke terms," such as "leak" or "crack," which will allow them to predict maintenance needs in the Navy's ongoing operations. By examining which logs contain many smoke terms, ongoing maintenance can specifically target the most at-risk equipment. In addition to text analysis, the team is also dedicated to developing visual dashboards that convey these findings at a quick glance.

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

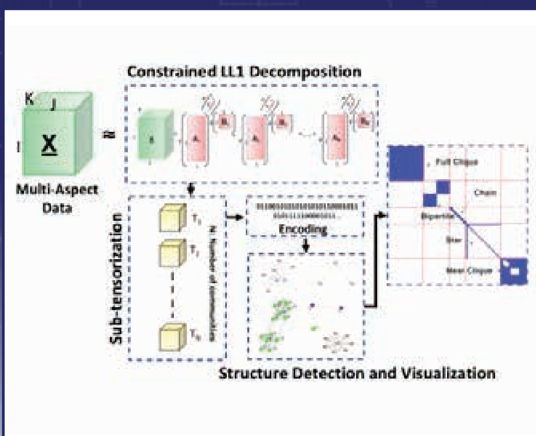
NEEC student developing new software.

NSWC Corona

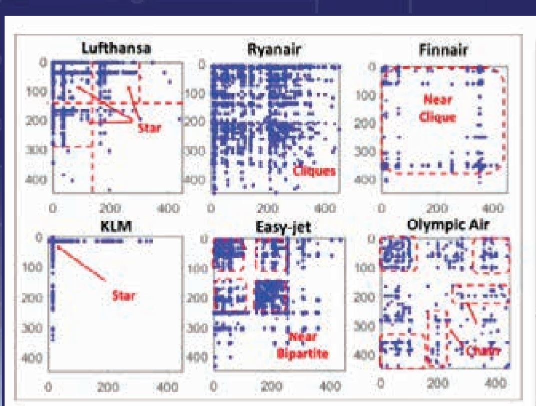
Big Multi-Aspect Data Mining via Scalable and Incremental Tensor Decompositions and Applications to Social Network Analysis

Professor:
Evangelos Papalexakis

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



NEEC analysis.



Airline results.

University of California, Riverside

The University of California at Riverside, in Riverside, CA, engages NEEC students on the research topic titled "Big Multi-Aspect Data Mining via Scalable and Incremental Tensor Decompositions and Applications to Social Network Analysis." Many real-world processes and phenomena produce big data with multiple aspects. For instance, in social networks, a who-calls-whom graph and a who-messages-whom graph are different aspects of human communication. Modeling and mining such multi-aspect data has been shown to yield more accurate results compared to studies that focus on a single aspect.

Prof. Papalexakis and his team are creating algorithms and tools for multi-aspect data analysis that are scalable and interpretable, enable incremental computation for continuously updated data, and most importantly are easy for practitioners to use. The algorithms developed in this project are applied to a high-impact real-world multi-aspect data scenario of multi-aspect social networks, where the task is to identify communities and patterns of normal and anomalous behavior from multi-aspect social network data. The significance of the work extends beyond social networks to general network and graph data but also to general multi-dimensional data processing.

The overall research output of the project has significantly advanced the state of the art in tensor methods. The major contributions include (1) novel semi-supervised techniques for tensor graph mining, (2) novel and scalable streaming tensor decompositions, (3) tensor embeddings for fake news detection, (4) introduction of the novel notion of concept drift in unsupervised streaming tensor mining. To this date, the project has produced 23 publications in top-tier data science venues such as ACM SIGKDD, SIAM SDM, ECML-PKDD, and ASONAM, which have, so far, accrued a total of 123 citations (according to Google Scholar), a metric which underscores the impact that the project has had on the research community in a very short amount of time.

NEEC students collaborating on their project.

NSWC Crane

Advanced Data Visualizations for Robust Machine Learning

Professors:
Dr. David Crandall,
Dr. Katy Borner

Students:
- **Undergraduate:** 11
- **Master's:** 5
- **PhD:** 3

IU students discuss the parameters used to fit the mathematical model to the training dataset.

Professor Crandall (upper right) hosts a virtual meeting with student researchers.

Indiana University

Progress in machine learning has led to impressive and successful advances in Artificial Intelligence over just the last few years. However, amid this excitement, there are warning signs and well-known failures in recent years. Machine learning relies on fitting complex mathematical models to training data. Deep artificial neural networks are the state-of-the-art: they consist of dozens of layers and millions of parameters. These networks are very powerful: when huge high-quality training sets are available, deep networks can readily learn a model for nearly any dataset. However, when training sets are small or biased, as often happens in practice, the networks "overfit" the training data while performing unexpectedly, erroneously, and even nonsensically on new examples. Moreover, given the complexity and black box nature of these models, it is usually difficult to debug or fix a failure.

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

Professor Crandall (far right) mentors student researchers working on the NEEC project.

NSWC Crane

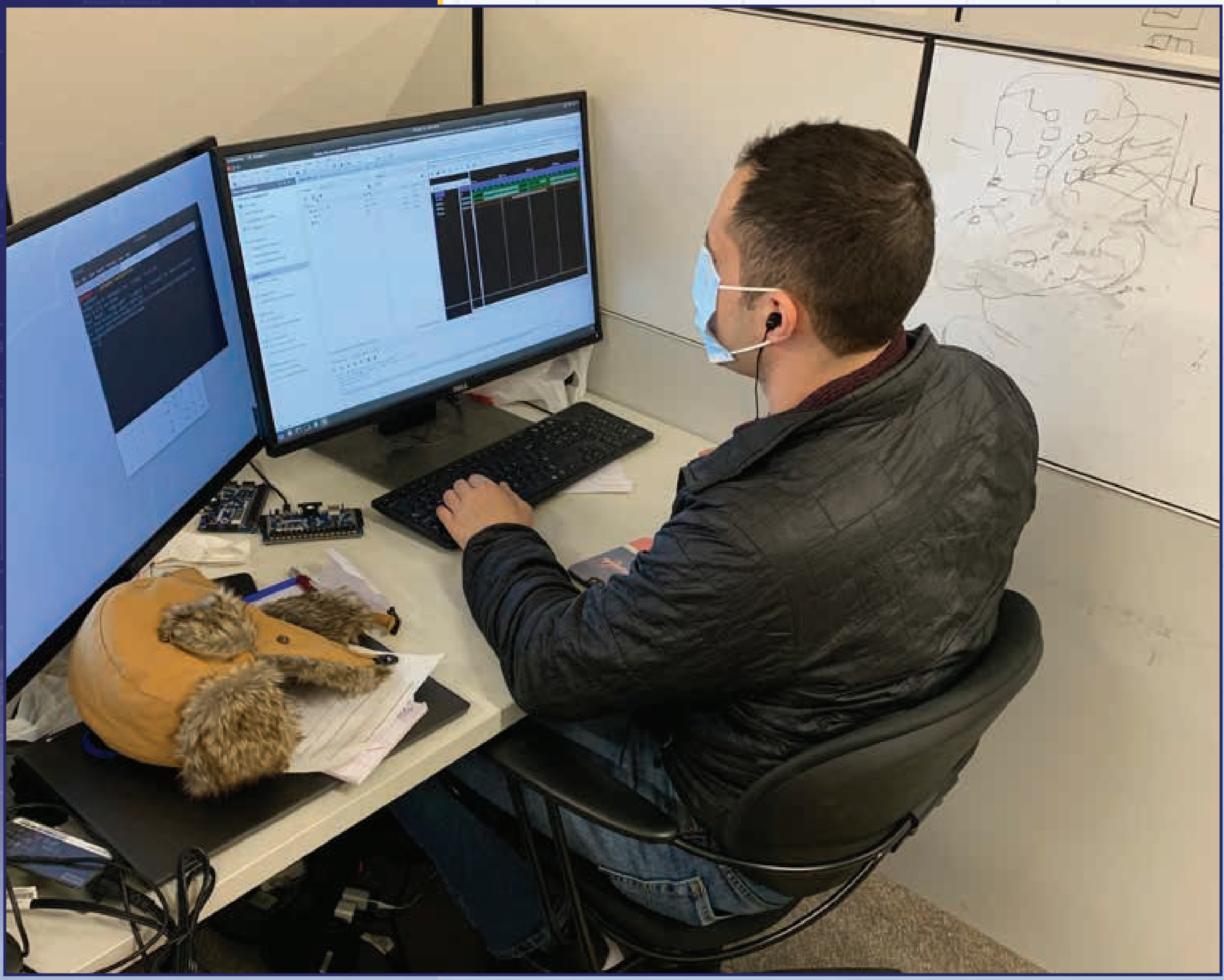
Reverse Engineering and Physical Verification Approach toFunctional Testing Tools For Field-Programmable Gate Arrays

Professors:
Dr. Andrew Lukefahr

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

Indiana University

This project will design and build Independent Functional Testing IFT tool suites for a Field-Programmable Gate Array (FPGA) by using a two-step process. As the architectural details for many FPGAs is 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.



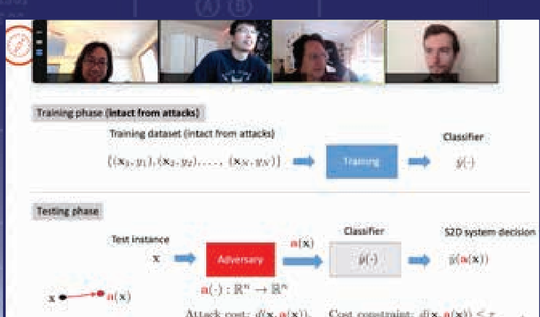
An IU student researcher works to develop IFT capability for FPGAs.

NSWC Crane

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

Professor:
Dr. Jinsub Kim,
Dr. Raviv Raich

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

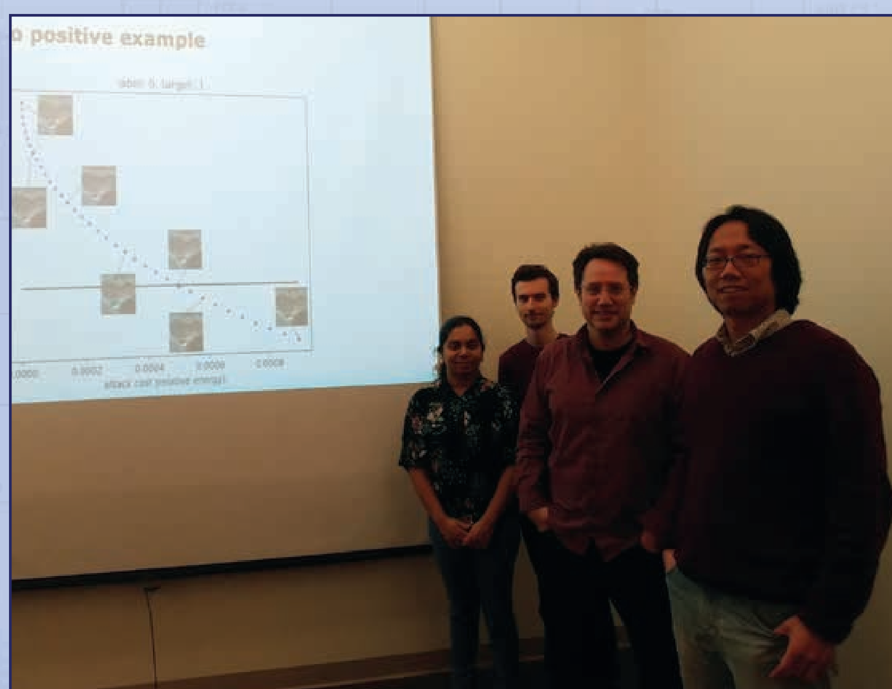


Professor Kim and Professor Raich host a virtual meeting with student researchers.

Oregon State University

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

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



Professor Raich (third from left) and Professor Kim (far right) present progress of the research to NSWC Crane stakeholders during the Project Quarterly Review meeting.

NSWC Crane

Harnessing Quantum Correlations for Quantum Sensing

Professors:
Dr. Ram Narayanan,
Dr. Matthew Brandsema

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

Pennsylvania State University

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

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

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

A PSU student researcher sets up the optical table in preparation for data collection.

NSWC Crane

Visualization of Repair Operations Management for Networked Systems Resilience

Professor:
Dr. Chenn Zhou,
John Moreland

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

PNW student researcher discusses the visualization parameters in a virtual meeting with Professor Zhou.

PNW student researcher discusses the approach to develop an intuitive interactive visualization method in a virtual meeting with Professor Zhou.

Purdue University Northwest

PURDUE UNIVERSITY NORTHWEST

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

PNW student researcher assessing the visualization technique used to enable intuitive understanding and improved decision making related to network resilience.

NSWC Crane

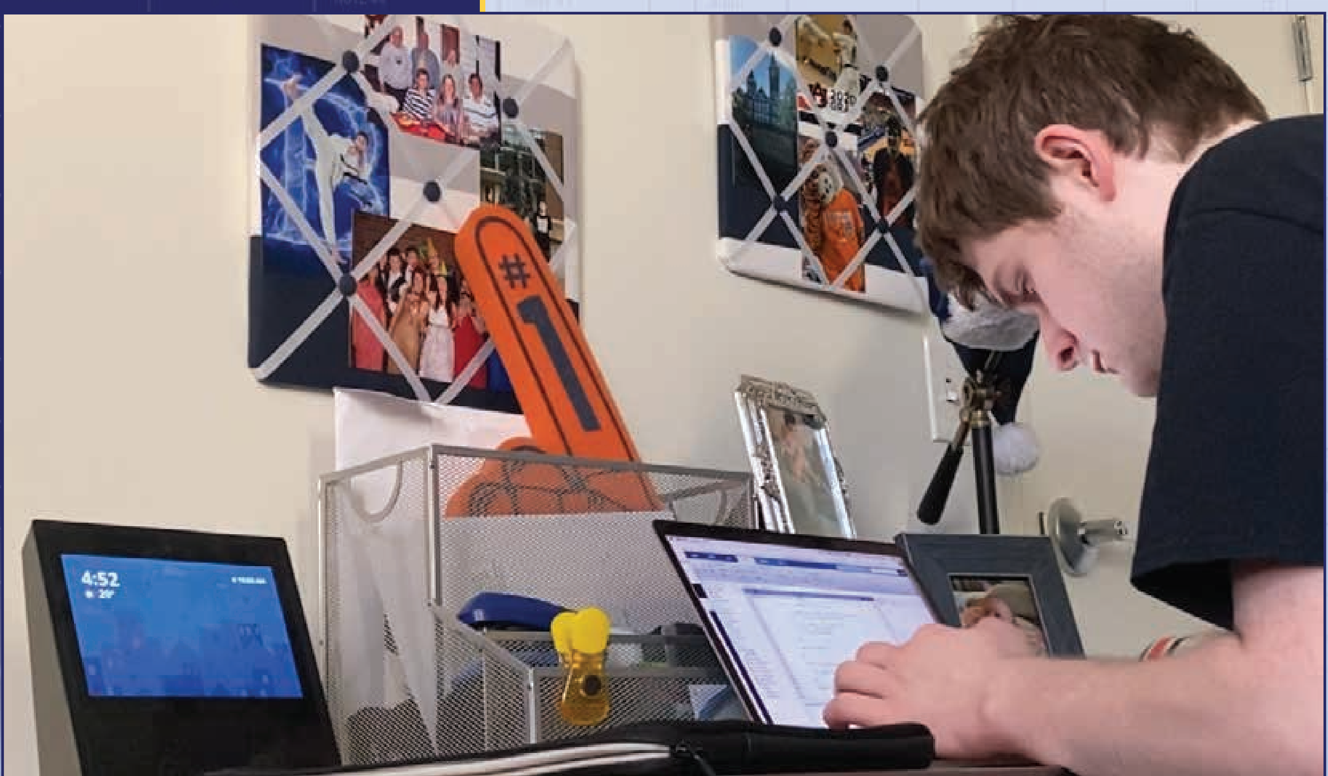
Modeling Complex Hypervelocity Flight Systems-of-Systems at the Component Scale

Professor:
Dr. Daniel DeLaurentis,
Dr. Shreyas Sundaram

Students:
- Master's: 1

Purdue University

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



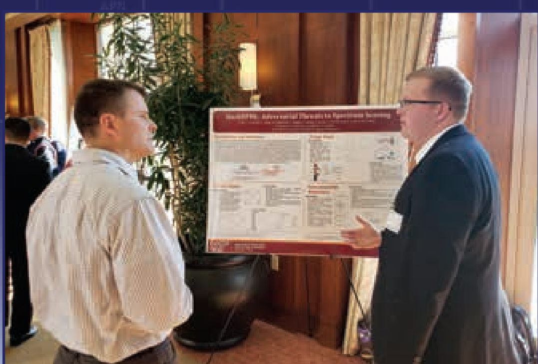
A Purdue University student researcher works to model and simulate advanced hypervelocity flight systems-of-systems at the component scale.

NSWC Crane

HACK RFML

Professors:
Dr. Alan Michaels,
Dr. William "Chris" Headley

Students:
- Undergraduate: 30
- Master's: 3



Va Tech student researcher presents a poster on the Hack RFML Project at the Va Tech Student Research Conference.

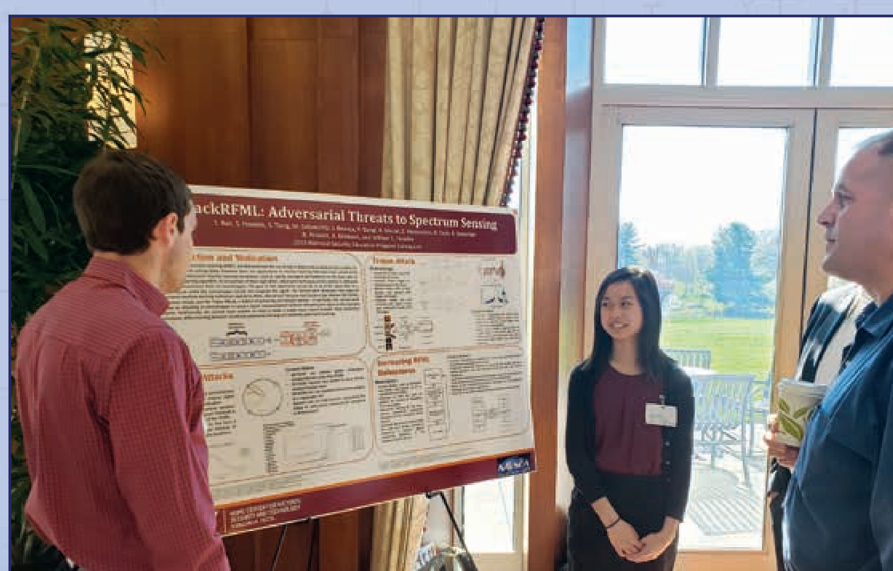
Va Tech student researcher presents a poster on the Hack RFML Project at the Va Tech Student Research Conference.

Virginia Polytechnic Institute and State University

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

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

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



Va Tech student researcher presents a poster on the Hack RFML Project at the Va Tech Student Research Conference.

NSWC Dahlgren

Manifold Learning for Subsequent Inference: Structure Discovery and Exploitation in Networks

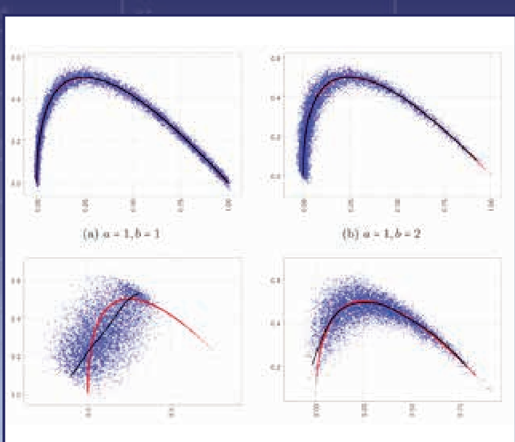
Professor:
Carey Priebe

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

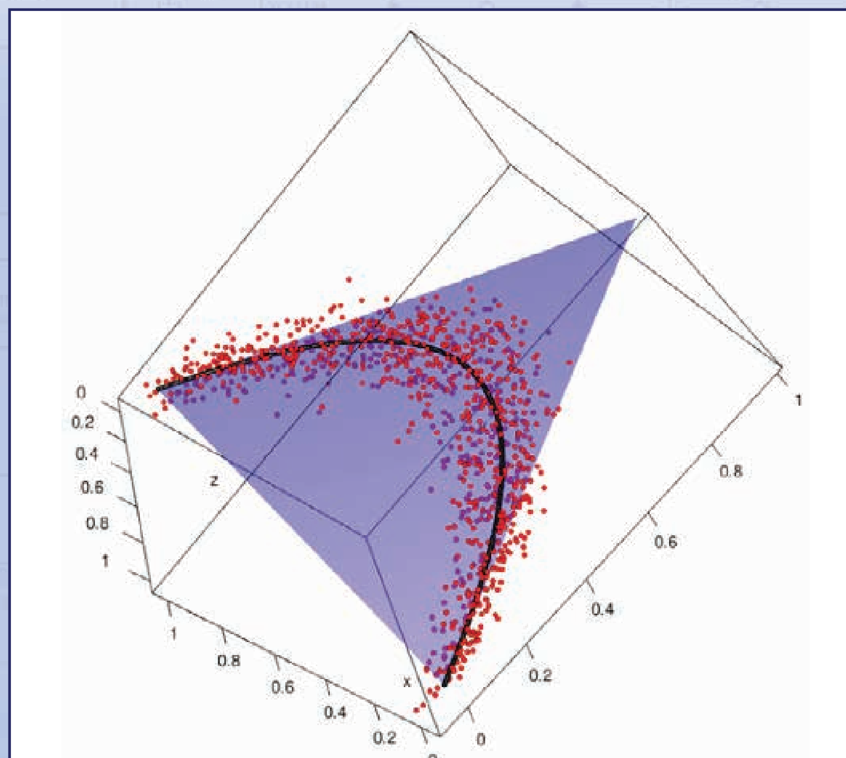
Johns Hopkins University

The purpose of this Naval Engineering Education Consortium (NEEC) funded project is to develop the tools needed to employ the data science discipline of manifold learning to identify structure in data networks and ultimately exploit the discovered structure for subsequent inference.

Many modern applications involve data in the form of a network, and the first step in addressing the associated exploitation task is to identify structure in the network, with the endgame being exploitation of discovered structure for subsequent inference. In this NEEC effort, JHU will formulate network structure discovery as a manifold learning problem in spectral decomposition space. JHU research faculty and students will perform theoretical, methodological, and practical investigations into appropriate manifold learning mechanisms for the facilitation of various subsequent inference exploitation tasks, including testing, estimation, classification, and regression.



Bezier curve estimates through the estimated latent positions for underlying distributions Beta(1, 1) (top left); Beta(1, 2) (top right); Beta(2, 5) (bottom left); and Beta(5, 5) (bottom right).



Phase space representation of manifold learning.

NSWC Dahlgren

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

Professor:
Emmanuel Arzuaga

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

University of Puerto Rico Mayaguez

Year 2020 activities included the development of Herd: A Cloud Environment to Support Live Container Migration and Monitoring. In particular, we developed an optimized live migration toolset for containers that can quickly migrate network-bound containers with filesystem support. We also designed and developed a lightweight resource monitoring tool (HerdMonitor) that supports live-migrating containers. Besides HerdMonitor, Herd includes a resource provision toolset that implements different container placement policies (HerdCompute + HerdControl).

The development of Herd involved a performance analysis of different live migration techniques to develop our system specific techniques. Finally, a methodology to process system and container resource information using artificial intelligence (AI) and machine learning was also explored. We designed a machine learning model for container resource provision and forecasting. Our efforts will now be focused on the development of a robust machine learning system that can use Herd to dynamically place containers in different compute nodes within a cloud environment. We will also include security measures in such a system.

Summer Program:
During the summer faculty research project, we provided a study and evaluation of the software-defined network (SDN) capabilities of VMware's NSX-T product. In particular, we configured a physical infrastructure using VMware vCenter, ESXi and NSX-T. We also performed different tests on the system to understand its main capabilities in terms of guaranteeing network isolation as well as the dynamic configuration capabilities that this SDN solution provides. We demonstrated that NSX-T is capable of working well at the required level, and we provided relevant documentation for its deployment and future adoption. We found that NSX-T is a very mature technology capable of providing a complete SDN solution that includes network isolation and high throughput. Additionally, we recorded an instructional video detailing the fundamental steps of how to set up and use NSX-T. Future directions of this work include the deployment of a large-scale environment in which NSX- T scalability can be further evaluated.

Professor Arzuaga and the University of Puerto Rico Mayaguez NEEC-student team.

NSWC Dahlgren

Toward Fully Electrically Reconfigurable Communication System

Professor:
Guoan Wang

Students:
- Undergraduate: 3
- PhD: 1

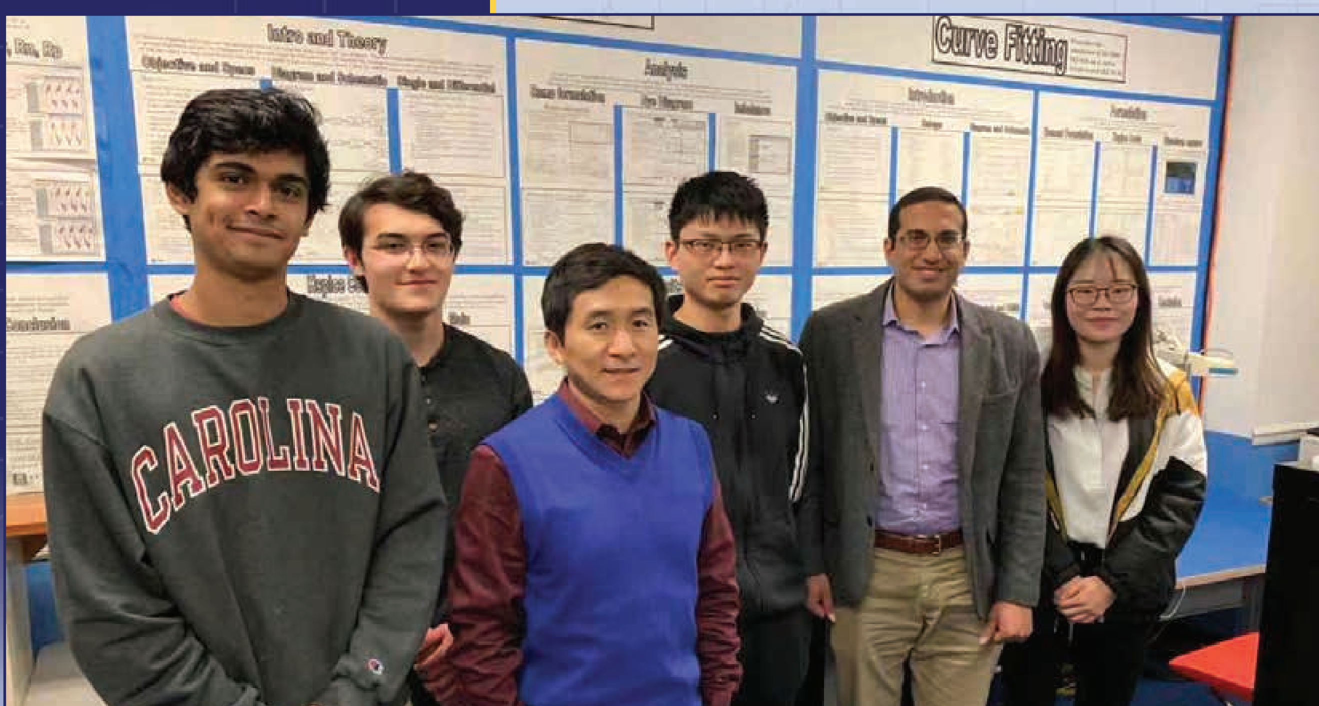
University of South Carolina

UNIVERSITY OF South Carolina
College of Education

The purpose of this Naval Engineering Education Consortium (NEEC) funded project is to develop novel radio frequency electronic components that will enable miniaturization and performance enhancement of high performance naval communication, electronic warfare, and radar systems.

Development of fully electrically reconfigurable RF and microwave technologies through interdisciplinary research at the material, device, circuit, and system level will be achieved with a thin-film-enabled engineered substrate. The engineered substrate is modeled and characterized with simplified transmission line structures to fully investigate the effects of embedded ferromagnetic thin-film patterns on the electrical properties of the implemented engineered substrate. Fundamental theoretical equations and a preliminary model have been generated to consider the effect of pattern dimensions, thickness, locations, and density. The efficacy of designing fully reconfigurable RF and microwave passives, with the demonstration of tunable frequency selective surface, antenna, and filters, is currently under investigation.

This NEEC effort is providing unique, hands-on experience for one PhD student, two undergraduates, and one visiting undergraduate summer intern. Support from NEEC provides great research and training opportunities for undergraduate students while enabling development of cutting-edge electromagnetic technologies. One undergraduate student has won the prestigious IEEE Microwave Theory and Techniques Society undergraduate scholarship.



South Carolina NEEC students and their professor

NSWC Dahlgren

Dielectric Breakdown in High Voltage Power Systems

Professor:
David Alan Wetz Jr.

Students:
- Undergraduate: 3

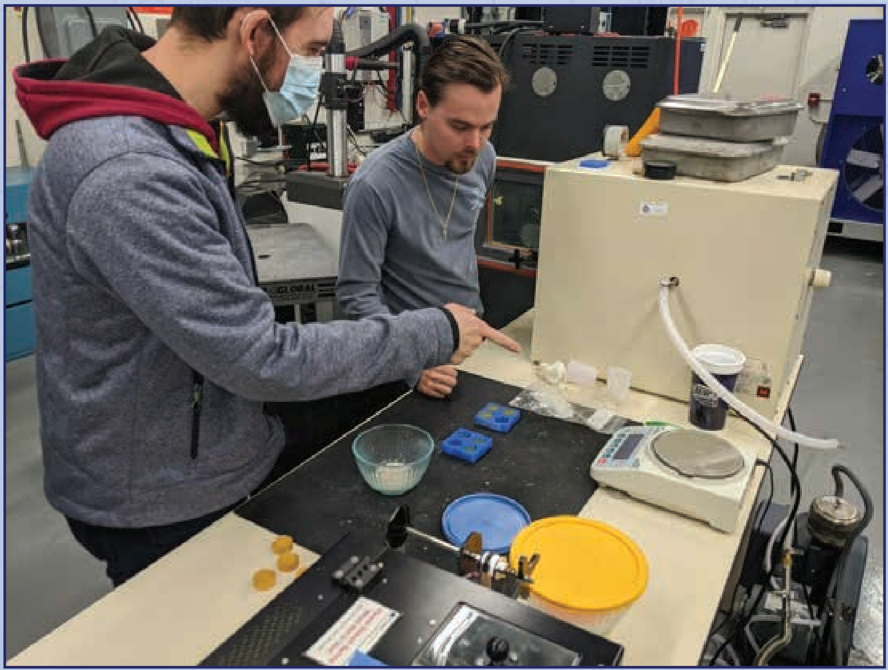
Student working on sensors attached to the output of a 150-kW electric motor-generator set.

University of Texas at Arlington

There are two related but distinctly different statements of work (SOWs) funded by this grant:

SOW 1: All fielded directed energy (DE) systems share common features, but each has unique requirements when it comes to energy stored, pulsed power supply type, operational voltage, operational current, pulsed duration, and repetition rate. The intent of this multifaceted project is to study alternative solid dielectric insulation materials that can be used throughout high voltage pulsed power systems. The work performed here aims to reduce the dependence on transformer oil and potentially reduce the engineering complexity, weight, and volume of fielded pulsed power systems. Special attention is being paid to studying existing Marx generator topologies and the use of new solid dielectrics in them for near-term results. Factors such as size, weight, shock, vibration, atmospheric, and environmental elements are being considered.

SOW 2: To field DE systems aboard the future fleet, the systems will rely heavily on the operation of several electronic stages to be successful, and all of them must perform reliably in demanding and changing environmental conditions. The students are identifying, procuring, and studying an electric motor-generator set capable of sourcing a 1-kVDC bus at roughly 40 kW. The electric motor is used to emulate an engine, and hardware in the loop (HIL) enables the procured hardware to emulate full fielded engine-generator sets. A 40-kW electric motor-generator set with integrated controls and rectifier has been procured and will be delivered in early 2021. The hardware will be integrated into an existing high voltage distributed generation testbed UTA has, known as the Intelligent Distributed Energy Analysis Laboratory (IDEAL), and it will be studied under practical loading scenarios. The result will be new knowledge to support NSWC-PD's zonal power system architecture development efforts.



Students working on making epoxy insulator samples.

NSWC Dahlgren

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

Professor:
David Alan Wetz Jr.

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

University of Texas at Arlington

The railgun community faces many challenges as they move toward fielding a high-energy, repetitive-rate system on a shipboard platform. One major challenge is preventing dielectric surface flashover across their insulators, especially in a polluted sea environment. Prevention of surface flashover, which is a less understood phenomenon, is very difficult, especially in quickly changing environmental conditions, and there are most often no manufacturer ratings that can be used in a design phase to prevent it. There are a few standards published that are used by the electric power industry to ensure creepage distance is sufficient, but they are vague and not always relevant to pulsed power applications.

This research is aimed at studying the surface flashover creepage standards that already exist and relating them to pulsed conditions relevant to a polluted railgun environment. Five different insulator materials are being evaluated, including polycarbonate, G9, G10, G11, and Delrin®. Each material is being polluted using carbon dust, white kaolin clay, and a salt fog. The research proposed here is assisting NSWC Dahlgren in their understanding of dielectric flashover in shipboard environmental conditions at voltages used by the Navy's EML program.

Students working with the testbed designed to replicate the International Electrotechnical Commission (IEC) 60112 standard.

Students assembling the insulation flashover testbed they built.

NSWC Dahlgren

Assisted Model-Based Systems Engineering (A-MBSE)

Professor:
Alejandro Salado

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

Virginia Polytechnic Institute and State University

The purpose of this Naval Engineering Education Consortium (NEEC) funded project is to develop a virtual assistant that evaluates a systems engineer's modeling work in real time and provides actionable recommendations.

Development of an AI- or expert-system-based virtual systems engineering assistant requires three principal tasks: identification of modeling gaps, behavioral modeling, and process design. In 2020, this NEEC project has continued testing the prototype rules developed in 2019, has explored the use of ontologies to develop reasoning capabilities, and has continued to create new rules. The prototype has been tested on an Earth observation satellite, and a test case of a satellite's telemetry, tracking and command (TTC) subsystem has been prepared. We have initiated the refinement of the intelligent advisor's code, addressing scalability and convergence issues. For process design, an undergraduate design project has developed an understanding of engineering practices that could benefit from modeling in the Navy enterprise and has collected information relevant to time/effort of certain practices (in particular, project reviews and requirements). Another undergraduate design project is developing a knowledge gathering and processing tool to feed knowledge from human engineers into the intelligent advisor.

Virginia Tech assisted model-based systems engineer team.

NSWC Dahlgren

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

Professor:
Binoy Ravindran

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

SSRG students including NEEC students and faculty members inspecting their rack-scale server testbed running Virginia Tech's Popcorn Linux operating system (NEEC-supported project).

Virginia Polytechnic Institute and State University

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

The Systems Software Research Group (SSRG) at Virginia Tech.

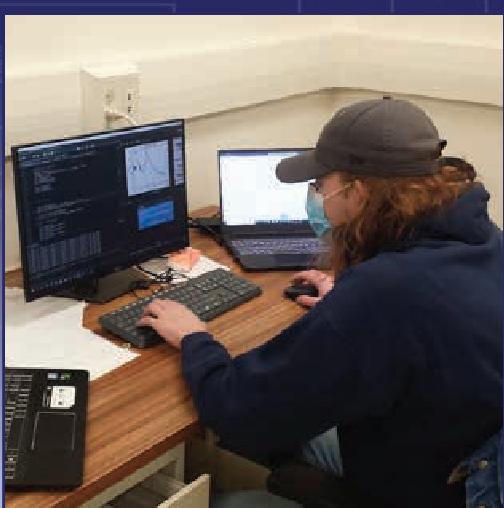
NSWC Dahlgren

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

Professor:
Wade Huebsch

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

MS graduate student in Aerospace Engineering working on his new design of a ballistic launcher for unstable flight articles. This is a blend of a 40-mm grenade launcher and a Mann barrel with additional safety features incorporated into the design. It will eventually be used to launch test articles that have an unstable flight trajectory, and the flight data will be recorded with a system of Vicon cameras.



MS graduate student in Aerospace Engineering working on developing a neural network that can help to predict the state space of an unstable flight object. The neural network is trained on existing experimental launches of unstable bodies in flight.

West Virginia University

Naval test and evaluation programs involving advanced threat missile systems require digital simulations of nontraditional flight modes. These nontraditional flight modes may be due to intentional aerodynamic design or by a damaged state. Either will result in unstable tumbling bodies, characterized by severely nonlinear, separated, and unsteady flows. These simulations must accurately replicate the actual rotational rates and fundamental character of the tumbling motion since these directly affect the signatures of the object that are presented to the weapon system as well as the probability for the damaged threat to reach its intended target.

These simulations should be sufficiently generalized to span multiple threat system variants, various states of damage, and multiple phases of flight to allow their ready use with evolving threats without requiring substantial rework. The simulations should also be aligned with current test assets used in Navy Operational Test (OT) testbeds. The Navy does not currently possess such simulations with sufficient fidelity to perform the required operational testing.

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

MS graduate student in Aerospace Engineering conducting research on the uncertainty of the Vicon Motion Capture System for different reflective marker geometries in both static and dynamic configurations.

NSWC Indian Head

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

Professor:
Dr. Sangram Redkar

Students:
- PhD: 2

Dr. Redkar testing EWD prototype.

Arizona State University

A new NEEC grant to Arizona State University addresses a critical need for information about warfighters exposed to chemical, biological, and radiological (CBR) attack. Simply speaking, "we are trying to answer the question — How are you? — before symptoms of sickness are visible in warfighters after they are exposed to CBR agents," says the principal investigator (PI) of the project, Dr. Prabha Dwivedi of NSWC Indian Head Division. She is collaborating with Dr. Sangram Redkar, Professor at Arizona State University, to design and develop an ear-wearable device (EWD) and algorithms that can capture warfighter health and environmental state.

The collaborators will team with the Naval Health and Research Center for testing and validation of the device, a Weapons of Mass Destruction Civil Support Team (91st CST WMD), and other end users to test EWD during their training and simulation exercises. The EWD effort uses the NEEC program to facilitate the active engagement of undergraduate and graduate students in contributing toward the development of novel technologies from inception to production and to enhance the DoD workforce with trained and competent personnel. With support from NEEC and the Defense Threat Reduction Agency (DTRA), the EWD project aims to ensure that the students are acquainted with the DoD areas of importance, such as warfighter readiness and capabilities enhancement, sensors and software development, and that they are trained to overcome technical challenges and seek solutions to real-world problems.

The EWD development is expected to support two PhD candidate students in each year of its 3-year duration.

In the first year, the team developed an EWD prototype that acquires EKG, SpO2, heart rate, and acceleration data. Each earpiece is customized to the wearer and 3D-printed from a digitized ear impression, minimizing the development time. The first generation of EWD systems will be tested at NHRC for performance, durability, accuracy, and reliability. The performance of the EWD system will be compared with the gold standard system. The EWD logs data in a local SD card and can stream data via WiFi using industry-standard encryption. Each EWD is IoT ready. The team also developed a data logging app on Windows and Mac to be used for remotely logging data. The PhD student working on the program successfully defended his prospectus and is expected to finish his PhD this year. The team also filed a provisional patent on the EWD.

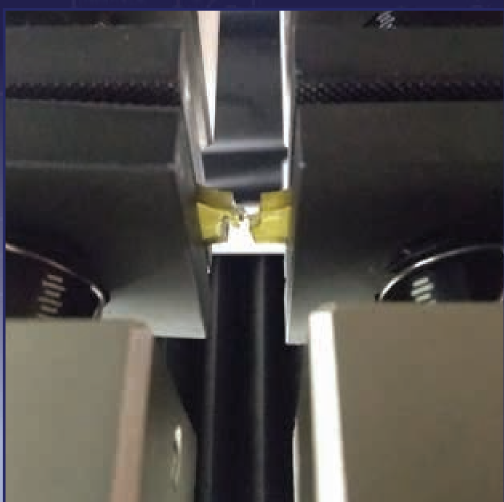
EWD prototype model.

NSWC Indian Head

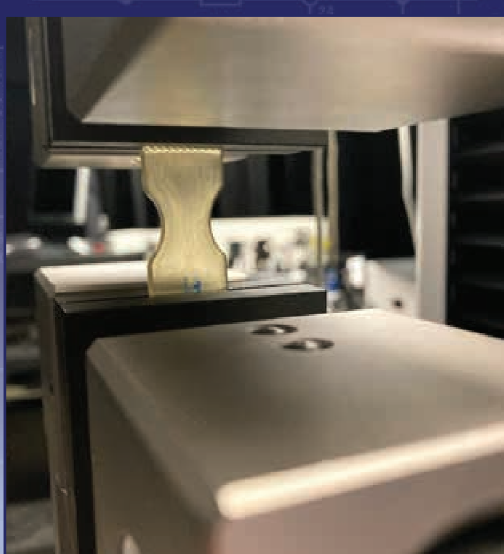
Determination of the Effects of Thermal and Mechanical Stress on PBX Binder Materials and the HE/Binder Interface

Professor:
James E. Patterson

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



Aged HTPB sample that failed at 3-mm extension.



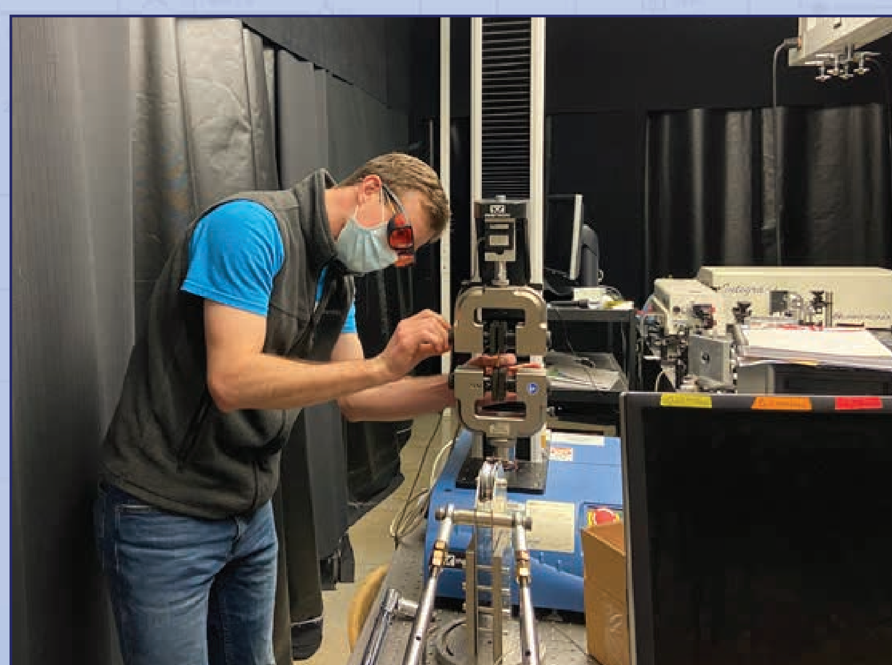
HTPB under mechanical extension of 8 mm.

Brigham Young University

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

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

Our work in the first year focused on fabrication and characterization of hydroxyl-terminated polybutadiene (HTPB) elastomeric materials. HTPB is a common binder material, and it is important to understand its mechanical properties and behaviors in the absence of any additives prior to the inclusion of additives. After working out reliable and reproducible procedures for preparing elastomeric samples, we began characterizing their response to mechanical stress and simulated aging.



BYU IH student loading a sample into the strength tester.

NSWC Indian Head

Production and Characterization of Additively Manufactured Steel Structures for Large Caliber Munitions Applications

Professor:
Grant Crawford

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

NEEC student participating in the AM process.

South Dakota School of Mines & Technology

SOUTH DAKOTA MINES
An engineering, science and technology university

Additive manufacturing (AM) has the potential to modernize munitions manufacturing, as it offers advantages such as rapid transition from prototype to volume production, faster material release, and potential for reduced manufacturing cost. AM techniques also offer inherent processing opportunities whereby the process may enable unique functionality (e.g., controlled fracture, functional gradient designs). To realize these benefits, significant research and development is required. One of the challenges is the AM fabrication of large metallic structures for munitions applications.

The South Dakota School of Mines & Technology is conducting research focused on the production and characterization of additively manufactured steel structures for munitions applications. The primary objectives of this effort are to (1) develop the process and capability for AM of representative geometries for large-caliber munitions and (2) develop the necessary process technology for AM of high-performance steels, with controlled fracture characteristics, commonly used in artillery applications.

To date, the team has demostrated AM of large steel artillery components using steel powder. The team has also succesfully developed, produced, and characterized a high-performance steel AM powder for artillery applications. Preliminary builds using the custom powder have been carried out and characterized. Finally, two post-build heat treatment methods have been evaluated.

NEEC student analyzing AM parts.

NSWC Indian Head

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

Professor:
Grant Crawford,
Lori Groven

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

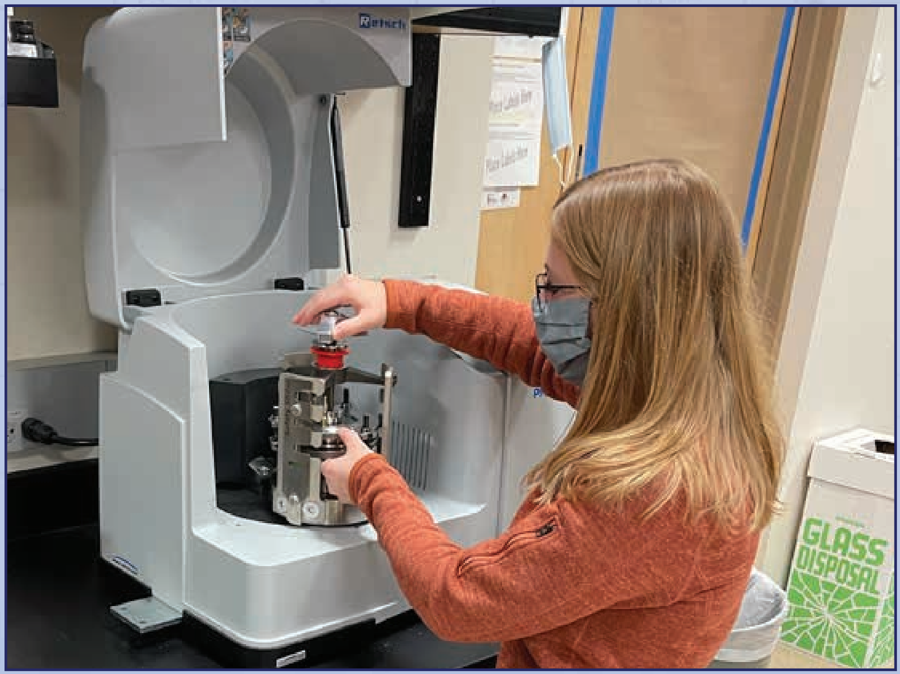
NEEC student.

South Dakota School of Mines & Technology

SOUTH DAKOTA MINES
An engineering, science and technology university

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

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



NEEC student.

NUWC Keyport

Human Performance Modeling

Professor:
Dr. Monifa Vaughn-Cooke

Students:
- PhD: 1

Students at the Hybrid-Systems Integration and Simulation Laboratory.

Hybrid-Systems Integration and Simulation Laboratory equipment.

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 that will use a combination of indirect (neuro-physiological workload) and direct (perceived workload, timing, accuracy) measures of cognitive workload to determine the impact of system design considerations on human performance. The results of this research will inform mixed reality design for control interfaces by reducing the risks associated with cognitive workload and improving system safety. In addition, recommendations for standardized metrics will be defined to integrate into system design validation activities to determine if customized designs are acceptable.

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

NEEC student working in the laboratory.

NUWC Keyport

Development of a Scalable Multi-UUV/ASV System: Autonomous Control/ Coordination/Evaluation and Underwater Perception

Professor:
May-Win Thein (PI),
Yuri Rzhanov (Co-PI)

Students:
- **Undergraduate:** 24
- **Master's:** 2
- **PhD:** 4

Autonomous Collaborative Multi-Platform System

University of New Hampshire

The development of autonomous control in surface and underwater vehicles continues to be in high demand, especially for operations where human involvement is not desired (e.g., in hazardous environments). Such applications include general surveillance and reconnaissance, search and rescue operations, and track and trail missions. In particular, a robust testbed is needed to test these autonomous systems with high-integrity field testing, especially when autonomous vehicle systems are distributed across different platforms (i.e., surface, underwater, and aerial). One of the purposes of this research is to continue to develop technology to enable autonomous control of multiple autonomous surface vehicle (ASV) and unmanned underwater vehicle (UUV) systems, creating a testbed to rigorously test autonomy software engines. The goal is to develop automatic feedback control techniques and real-time, nonlinear systems identification methods to ensure the autonomous system is, in fact, robust and reliable even in the presence of environmental hazards and varying sea states.

The development of autonomous marine vehicles, particularly for the coordination of autonomous UUVs, is particularly sought. The challenge is to enable the ability of the vehicle to reliably perceive its environment for self-localization and area mapping, particularly for the purposes of obstacle/ collision avoidance. For this purpose, the PI proposes two research goals: (1) to develop a cost-effective sensor system to enable autonomous coordination of multiple UUVs that is capable of ensuring reliable vehicle autonomy and multi-UUV collaboration and communication; and (2) to develop an Artificial Intelligence (AI)-based simulation testing environment (using a Fuzzy Logic system) to evaluate vehicle perception capabilities and its performance effects on overall system autonomy. The combination of the results of these two efforts will enable the improved and optimized design of a multiple-UUV autonomous network for subtasks such as self-localization and area mapping, automated path planning with obstacle/collision avoidance, monitoring of changing/hazardous environments, and mission payload delivery.

ASV Testing (UNH Chase Ocean Engineering Building)

NUWC Keyport

Seamless Manufacturing and Remanufacturing for Foundry Industry via Laser-based 3D Printing and Surface Cladding

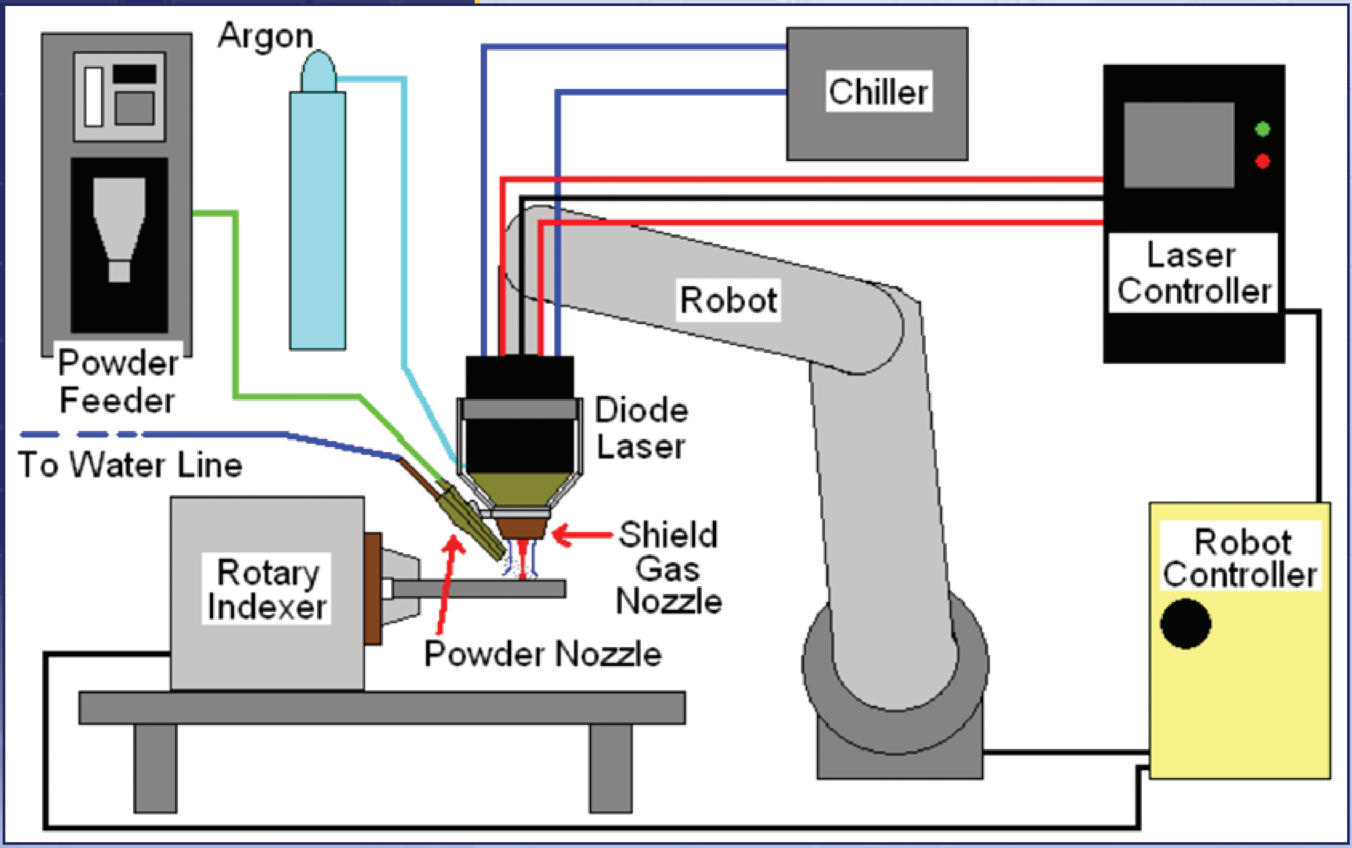
Professor:
Yung C. Shin

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

Purdue University

PURDUE UNIVERSITY

The goal of this project is to develop cost-effective and seamless technologies for rapidly building and repairing various structural components made of different materials by laser additive manufacturing and cladding. The cladding layers will be designed to provide optimum environmental and wear resistance. The resultant microstructures and compositions are characterized by various material characterization techniques, and mechanical properties such as hardness and ultimate tensile strength are analyzed. Concurrently, modeling of the physical processes is carried out to gain a further understanding and to optimize the process conditions. The outcome of this project will be useful to rapid repairing of various ship components.



The high-level design of the NEEC project instrumentation.

NUWC Keyport

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

Professor:
Hadi Fekrmandi (PI),
Randy Hoover (Co-PI)

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

South Dakota School of Mines & Technology

SOUTH DAKOTA MINES
An engineering, science and technology university

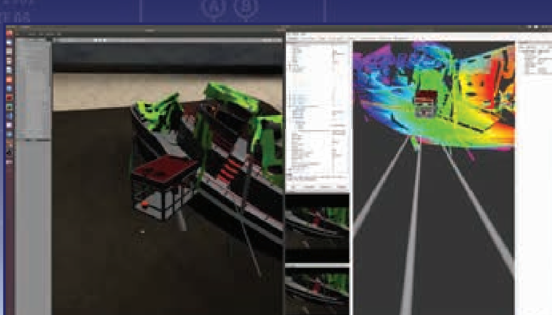
In modern unmanned underwater vehicles (UUVs), data is collected from a multitude of sources within the swarm. In a swarm of UUVs, the agents each have local world views and observe only a fraction of the world model. The overall task is to fuse/integrate their individual data to construct an integrated, global view of their operational space. While world view modeling through swarm data integration has seen significant advancements within the ground-based and aerial-based robotic systems, this type of modeling for UUV systems trails behind because the coordination of a team of UUVs for cooperative function in underwater environments is more challenging than for ground or aerial multi-agent robots.

South Dakota Mines and NUWC Keyport are collaborating to develop self-localization and intelligent mapping (SLIM) for multi-agent systems of UUVs operating in the underwater domain. The project will develop a distributed state estimation for decentralized localization and control of multi-UUV teams with resilience and cooperative capabilities.

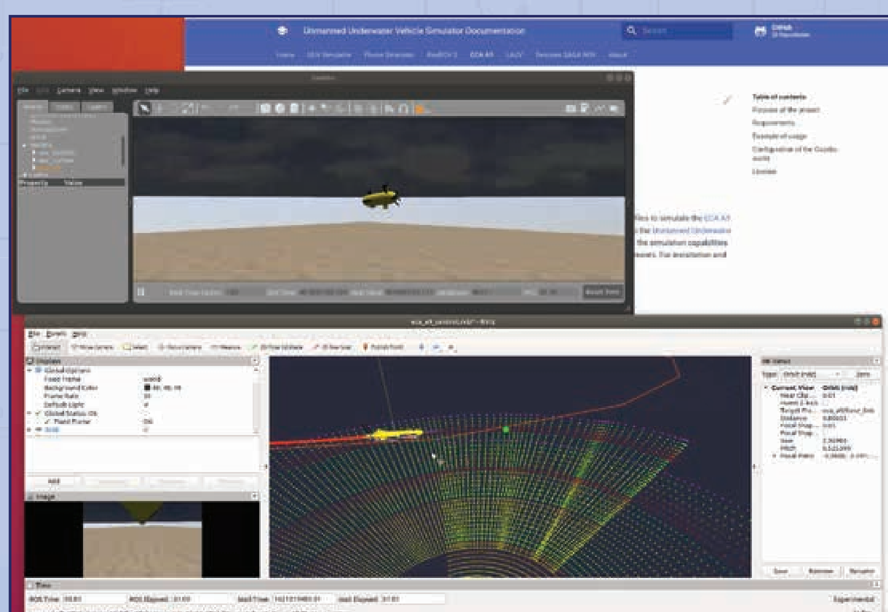
The SLIM research has the following objectives:

- Expand the Navy's UUV capabilities through artificial intelligence to static undersea sensors and/or dynamic undersea groups to improve autonomous perception and data fusion in an effort to generate world models from individual sensing while localizing the sensors and UUV swarm within the model.
- Advance the Navy's ability to fuse data from static and dynamic underwater sensors to be used in the generation of world models, self-localization, and autonomous planning and decision making, as encountered within the U.S. Navy as well as in the entire DoD battlespace.

NEEC Fellow students and advisors implementing DSE over ROS robot platforms



Lidar



Sonar

NUWC Keyport

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

Professor:
Dwayne Arola

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

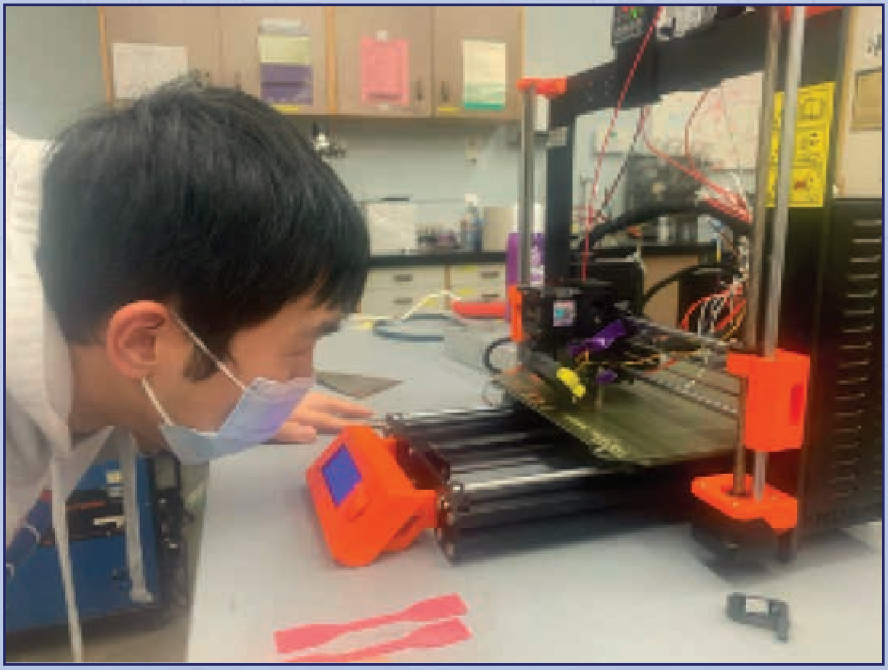
NEEC student analyzing the polymers.

University of Washington

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

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

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



NEEC student working on the AM process.

NUWC Keyport

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

Professor:
Ashis G. Banerjee, Santosh Devasia

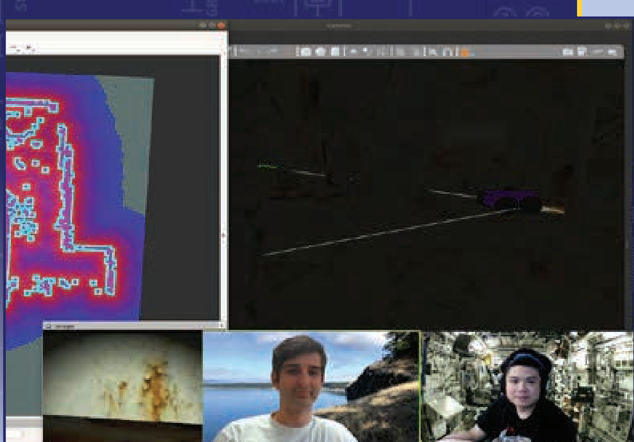
Students:
- Undergraduate: 1
- Master's: 2

University of Washington

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

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

Humans should also be involved in the control loops of the robots, for example, in using teleoperation to exploit human flexibility and knowledge to handle uncertainties in the constrained spaces. However, teleoperation can be slow and may impose restrictions on the scalable deployment of robots. Therefore, we will examine the use of mixed-initiative traded control between autonomy and teleoperation based on the estimated failure probability of the pure autonomy mode to ensure safe, stable actions while performing the tasks in an optimal manner. All these research efforts would lead to the goal of educating the next-generation workforce in Navy shipyards who would be skilled in implementing the latest robotics technologies.



Remote collaboration between the students working on the NEEC project.

Autonomous mapping of a poorly-lit, rusty water tank by an accurately localized ground robot.

NUWC Keyport

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 event such that a solution may be implemented prior to actual obsolescence.

The goal of this project is toward a more proactive obsolescence management approach by looking at the equipment lifecycle and combining that with predictive modeling for hardware or mechanical parts. The result will be potential new insights or features that will allow obsolescence management to continue to move from a reactive to a proactive approach, addressing problems before they occur. Of particular interest is the post-procurement part of the life cycle costs (redesign, re-hosting and re-qualification) because these costs may contribute as much or more to the total life cycle cost as the initial cost of hardware and software. The team will develop risk-based forecasting algorithms for implementation into NUWC Keyport's Obsolescence Management Information System (OMIS™).

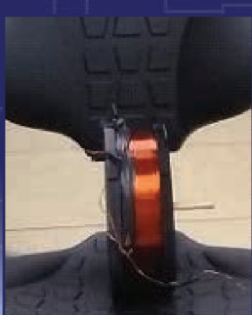
Proactive obsolescence plans will help future submarines.

NUWC Keyport

Wireless Communication for Unmanned Underwater Vehicles using Magnetic Induction

Professor:
Dr. Murari Kejariwal

Students:
- Undergraduate: 4



NEEC instrumentation.

Washington State University

Communication with underwater unmanned vehicles (UUVs) is very important for the success of their missions. The missions may involve, for example, surveying desired sites and collecting relevant data; returning to home stations and wirelessly downloading collected data; or coordinating activities between various UUVs during their mission. The required communication range may vary from short range (nearfield) to medium range in nature. Data collection and downloading that are power efficient and fast are very important for the success of these missions.

In the first phase of this project, activity concentrated on investigating a magnetic induction mode of communication—its usefulness and limitations in a seawater environment. Improvement in the power efficiency of the data rate in nearfield communication will be studied during the fall and spring semesters. However, the Multi-input Multi-output (MIMO) communication mode will be studied in the subsequent phases. Theoretical simulated results will be verified in the experimental section of this project. A small, compact, low-power system is being designed and constructed in this phase of the development.

This project, nicknamed Remote Aquatic Mag-coupled Real-time Oscillatory Dispatch System (RAMROD system), is a wireless communication system that aims to leverage the beneficial properties of magnetic induction to transfer information in submerged seawater environments. The system is designed to implement a frequency shift keying (FSK) protocol that will allow data rates up to 64 kb/s. The prototype is under construction. The completed portions of the system have shown early promising results.

One of the senior students is shown working on the development of the communication system using magnetic induction. They are using the magnetic induction coil as shown in the picture on the right side.

NUWC Newport

Improved Robot Autonomy Using Neuromorphic-Based Stochastic Computing

Professor:
Dr. Scott Koziol

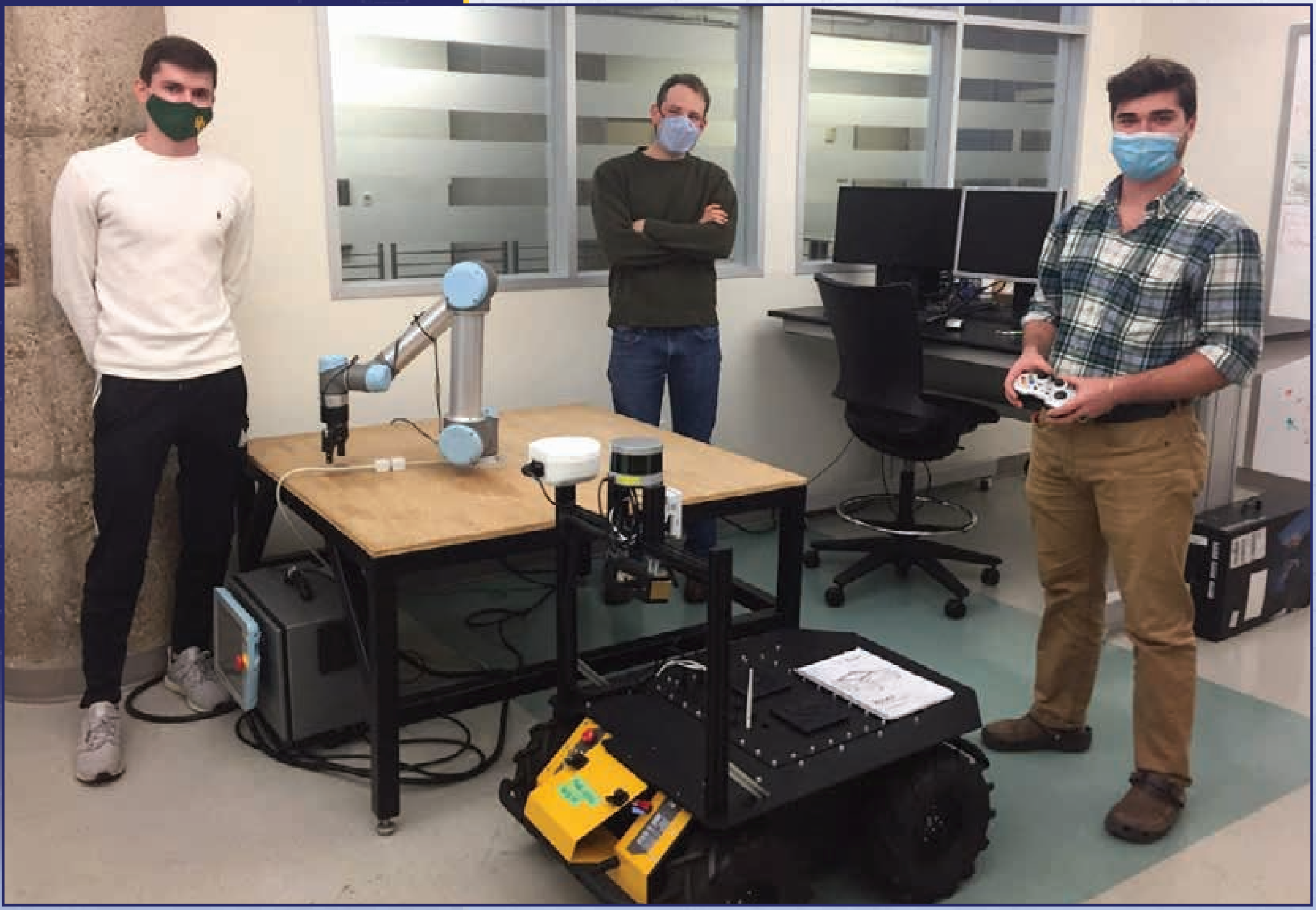
Students:
- **Undergraduate:** 3
- **Master's:** 5
- **PhD:** 1

Baylor University

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

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

The system-level problem being addressed is to provide better onboard computation systems for small autonomous robots performing missions such as surveying. This is important because onboard computation is limited by size and power constraints, and computing is a critical capability for autonomous systems performing these missions. If integrated into onboard systems, improved computation has the potential to improve navigation, acoustic localization, or underwater sound tracking in challenging environments.



Three Baylor University NEEC graduate students pose with a Universal Robots UR5 robot arm and a Clearpath Robotics Husky unmanned ground vehicle in the Baylor Neuromorphic & Robotic Systems research lab. Robots such as the Husky could serve as a test platform for the electronic systems developed for NEEC.

NUWC Newport

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

Professor:
Timothy C. Havens,
Andrew Barnard

Students:
- **Undergraduate:** 7
- **PhD:** 1

Michigan Technological University

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

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

Students discussing the camera housing for tracking snowmobiles and other on-ice noise sources on the Portage Canal outside the Great Lakes Research Center.

Michigan Tech students deploy the acoustic sensing unit for taking measurements of on-ice traffic outside the Great Lakes Research Center.

NUWC Newport

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

Professor:
Gila Stein,
Mike Kilbey

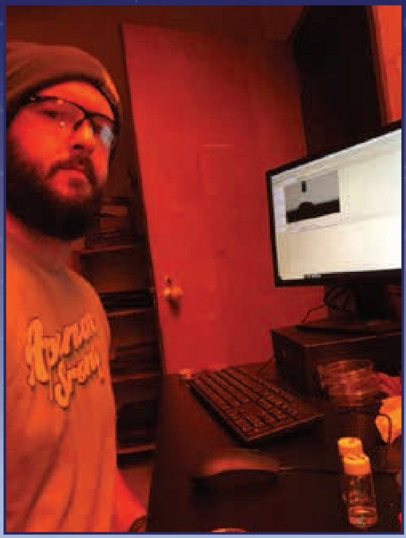
Students:
- Undergraduate: 2
- PhD: 2

University of Tennessee, Knoxville

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

The goal of this research program is to develop non-biocide-release elastomeric coatings that protect large-area surfaces from marine fouling. The approach is based on multifunctional surface-active macromolecular brushes (SAMBs) that spontaneously accumulate and self-organize at the surface of an elastomeric coating. This platform offers several advantages over traditional elastomer design. First, surface functions are largely decoupled from coating mechanics. Second, surface heterogeneities are controlled at both the nanoscale and microscale, so the design attributes that frustrate settlement and adhesion of marine organisms can be systematically interrogated. Third, multiple functions are encoded in a single platform (fouling-release, anti-fouling, and anti-microbial), and formulations may be optimized to address geographical diversity in marine environments.

Our objective is to develop structure-property relations that explain how chemical, mechanical and topographic heterogeneities in these systems will affect antifouling character. To this end, we are synthesizing a suite of SAMB additives based on four types of monomer: (1) a fluorinated chemistry that is low energy for fouling release, but stiff and Teflon-like; (2) a siloxane chemistry that is both low-energy and low modulus for fouling release; (3) a hydrophilic chemistry that is antifouling and also serves as a precursor for the fourth type; (4) anti-microbial functions. The additives are incorporated in a commercial thermoplastic elastomer. Films are prepared by casting from a green solvent. Biofouling assays are performed at the University of Tennessee, Knoxville for preliminary screening, and marine fouling assays are planned for the summer 2021 internship program.



A student is measuring water contact angle on the surface of an elastomer film.

Students working on purification of reagents for SAMB synthesis.

NUWC Newport

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

Professor:
Arun Shukla

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

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

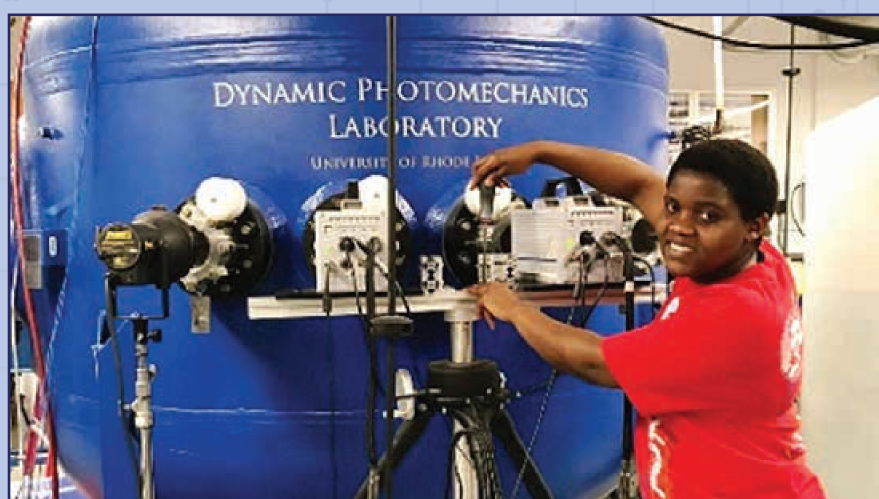
University of Rhode Island

THE UNIVERSITY OF RHODE ISLAND

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

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

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



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

NUWC Newport

Bioinspired Physical Deep Learning Paradigm for Sonar Sensing in Cluttered Environment

Professor:
Rolf Müller

Students:
- **Undergraduate:** 12
- **Master's:** 1
- **PhD:** 2

Making a flexible soft-robotic pinna using a silicone mould.

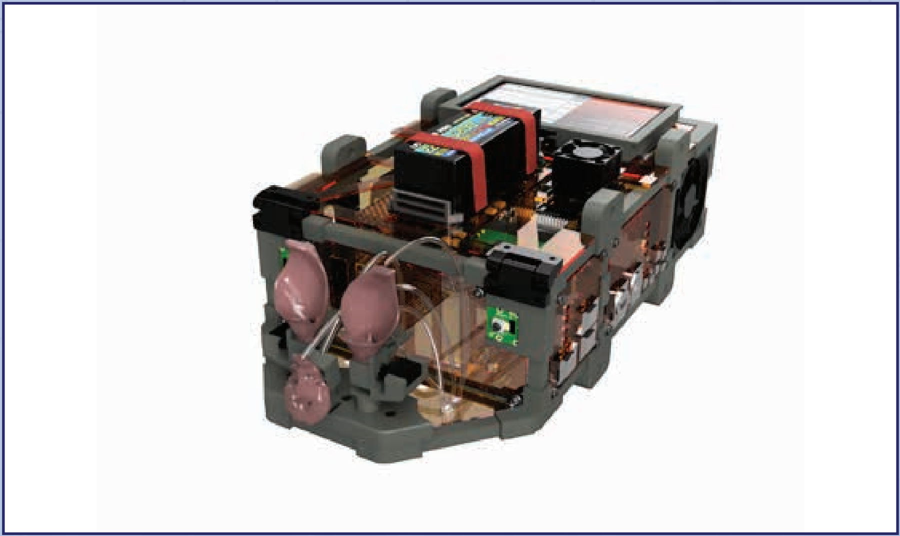
Virginia Polytechnic Institute and State University

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

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

In addition to developing the mechanical, electrical, and software aspects of this project, work is underway to implement machine learning algorithms on the biomimetic soft robot that will eventually integrate control of the peripheral dynamics and signal analysis. At present, approaches for analyzing "clutter echoes" for the purpose of identifying sonar landmarks and finding passageways in natural environments are under development. The targeted combination of controlling information encoding in the physical domain and signal analysis in the computational domain could have a transformative impact on the ability to handle difficult sonar sensing scenarios.

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



Rendering of the CAD model for the current prototype of the biomimetic sonar head with soft-robotic, pneumatic actuation.

NSWC Panama City

Geomagnetic and Bathymetry Based Navigation System for an AUV

Professor:
Manhar Dhanak,
Edgar An,
Pierre Beaujean

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

Students attempt to retrieve a REMUS 100 UUV after experiments.

Florida Atlantic University

FAU
FLORIDA ATLANTIC UNIVERSITY

There exist navigation inaccuracies in predicted paths arise through environmental disturbances, including currents. If available, acoustic transponders enable the AUV to determine its position relative to a surface ship or buoys and thereby enable positional corrections. An alternative approach is geophysical navigation, involving utilization of environmental features for localization, using sonar, stereo cameras, or magnetic field maps. Here, we investigate development of algorithms for AUV navigation using INS and a DVL with positional correction based on geomagnetic and bathymetric information. The method is based on the geomagnetic navigation of certain aquatic animals and utilizes available a priori reference maps of geomagnetic and bathymetric fields. Algorithms involving a Kalman filter, will be developed that primarily use INS plus a DVL to navigate to a destination, but make required corrections to the path through measurement of the local bathymetry and magnetic fields using onboard sensors and matching the measured data to available onboard maps of the bathymetry and geomagnetic field. Experiments will be performed first to obtain geomagnetic and bathymetric data in the vicinity of FAU, SeaTech, or at a preferred location. Simulations will be performed using a modeled system to evaluate the performance of the navigation method, both in the absence and in the presence of currents. The developed system will then be implemented on an available REMUS AUV, and navigational experiments will be carried out to determine the performance of the vehicle's navigation in the field.

Students launch a REMUS 100 vehicle from a research vessel in order to conduct a magnetic navigation experiment.

NSWC Panama City

Understanding Cybersecurity Implications of Using and Protecting Unmanned Aerial Vehicles

Professor:
Mike Burmester,
Daniel Schwartz

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

Florida State University

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

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

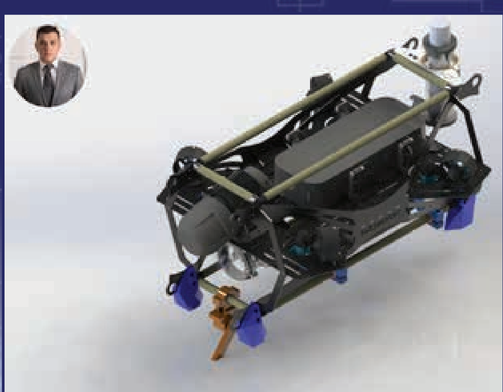
Students discuss their research progress with Prof. Michael Burmester on cybersecurity for unmanned systems.

NSWC Panama City

Collaborative Maritime Systems

Professor:
Warren Dixon,
Eric Schwartz

Students:
- **Undergraduate:** 22
- **PhD:** 3



Student discusses a CAD model of a research UUV via Zoom.

University of Florida

UF | UNIVERSITY of FLORIDA

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

The University of Florida Robot X team with their WAM-V unmanned surface vessel.

NSWC Panama City

Understnding Deep Learning Architectures with Information Theory

Professor:
Jose C. Principe

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

University of Florida

Our effort seeks to improve the training, hyper parameter selection, and generalization ability of learning machines using a combination of machine learning and information theoretic concepts. Our ultimate goal is to improve the available quantification tools to give more confidence to designers and users alike and improve the transparency of this class of algorithms. Quantifying the generalization ability of supervised learning machines is a difficult problem that is associated with their capacity. In this proposal, we propose a different framework by blending machine learning and information theory. We have recently utilized an information theoretic learning (ITL) framework (proposed by the PI) to train a stacked autoencoder (SAE) using an ITL constraint (ITL-AE). We believe that ITL can provide the needed mathematical underpinning to quantify information transfer in deep architectures and seek optimal topologies that generalize the most for unseen data belonging to the same distribution as the training set. The Navy is increasingly more dependent on information systems using deep learning, so providing more explainability regarding the computation and more ways to optimize the training is of great importance.

Student discusses his research related to machine learning hyper parameters via Zoom.

NSWC Panama City

Robust and Reversible Deep Networks

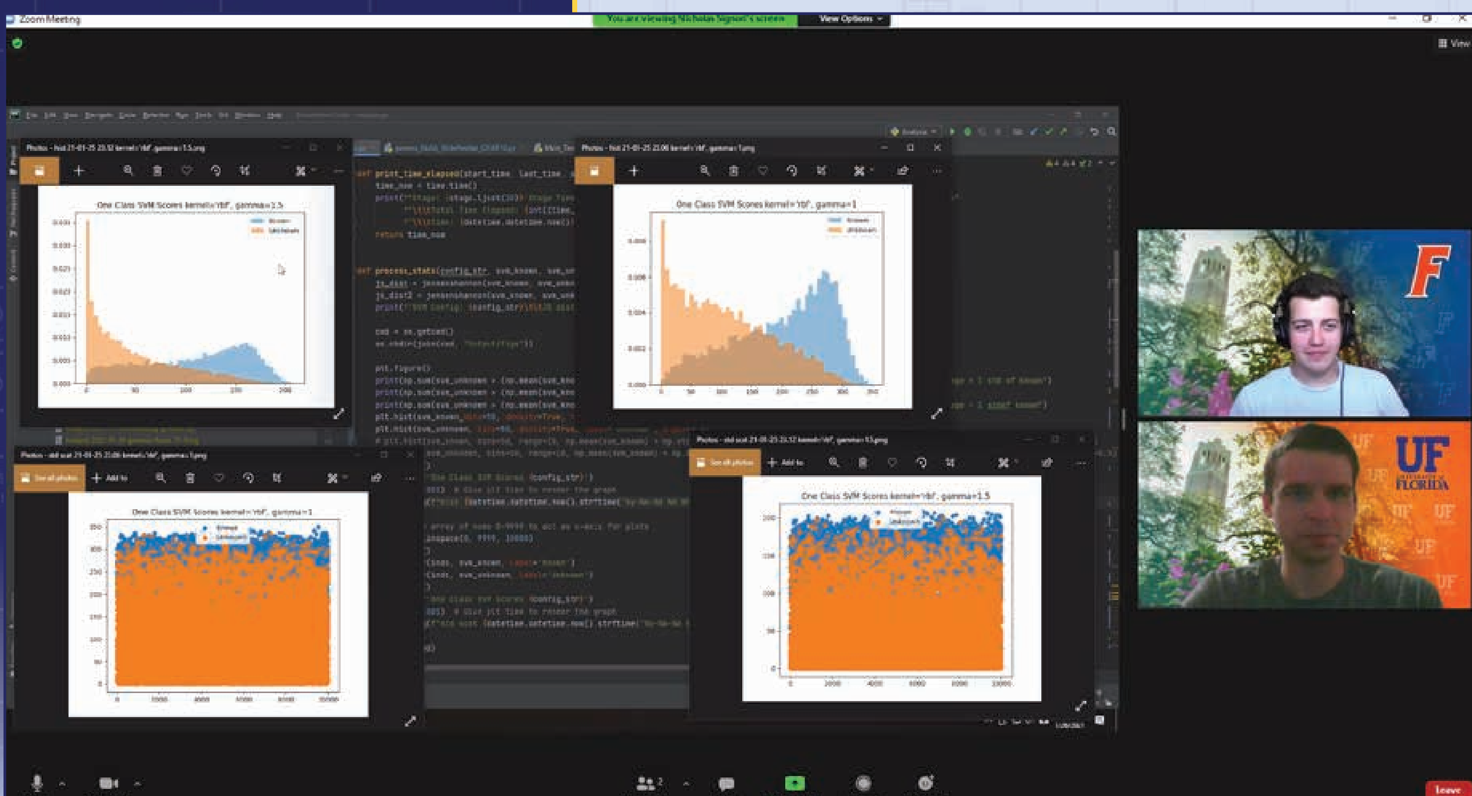
Professor:
Alina Zare

Students:
- Undergraduate: 1

University of Florida

UF UNIVERSITY of FLORIDA

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



Students meet via Zoom to discuss the development of NuSA, a deep learning null space analysis approach for outlier detection.

NSWC Panama City

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

Professor:
Ananya Sen Gupta

Students:
- PhD: 1

University of Iowa

The goal of our project is to develop a robust physics-cognizant mathematical framework to represent and differentiate different classes of acoustic echoes from proud, buried and semi-buried targets. More generally, we aim to detect and disambiguate potentially overlapped spectral features from diverse undersea scatterers using active sonar signaling for classification of underwater sonar targets. We also propose to employ similar methods for underwater acoustic channel interpretation as part of naval communication systems to aid dynamic node placement of acoustic sensors. The bold departure in our effort from the current state-of-the-art lies in employing geometric signal processing rather than algebraic and/or statistical techniques (e.g., subspace separation methods) to differentiate classes of echoes. The key intuition is to represent nonlinear overlap between spectral features by using geometric braid and knot theory, which is mathematically well suited to encode/decode overlapped “shapes” that may undergo smooth deformations over time, space, frequency, and other parameters. Our innovations lie in integration of acoustic scattering physics with sonar spectral analysis and are, therefore, naturally suited to interface between domain knowledge and emergent techniques in machine learning. We achieve this by harnessing Gabor wavelets that match models of elastic wave orbits with manifold signal processing techniques that embed braid and knot encoding into sonar signaling schemes. This allows human expert interpretation of learned features, which can provide critical and nuanced understanding of why different learning techniques select different elements of spectral morphology. In particular, our methods are aimed at (1) detecting features that morph smoothly across different scattering angles and ranges, and (2) unraveling overlapped features that exhibit distinct spectral topology and therefore, potentially represent different classes of acoustic echoes. Results of this project will also lead to dynamic interpretation of acoustic scattering signatures, which will potentially aid adaptive node placement.

NSWC PCD Researcher and NEEC Director Dr. Matthew Bays discusses research with Prof. Ananya Sen Gupta’s Lab at a NEEC Virtual Site Visit.

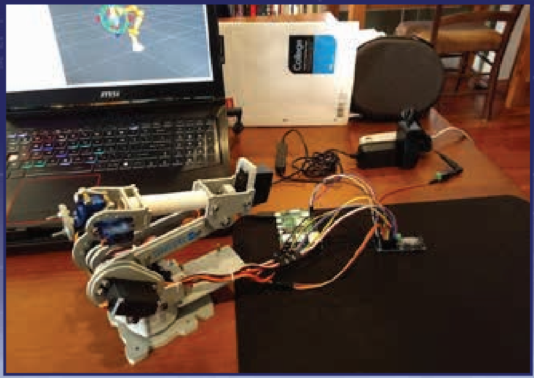
NSWC Panama City

Algorithm Development for Ultrasonic Sensing System for Naval Mine Detection.

Professor:
Jason Mitchell,
Brett Byram,
Jack Noble

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

Student troubleshooting the electronics for an underwater manipulator.



Robot Manipulator tracking with virtual visualization software.

Vanderbilt University

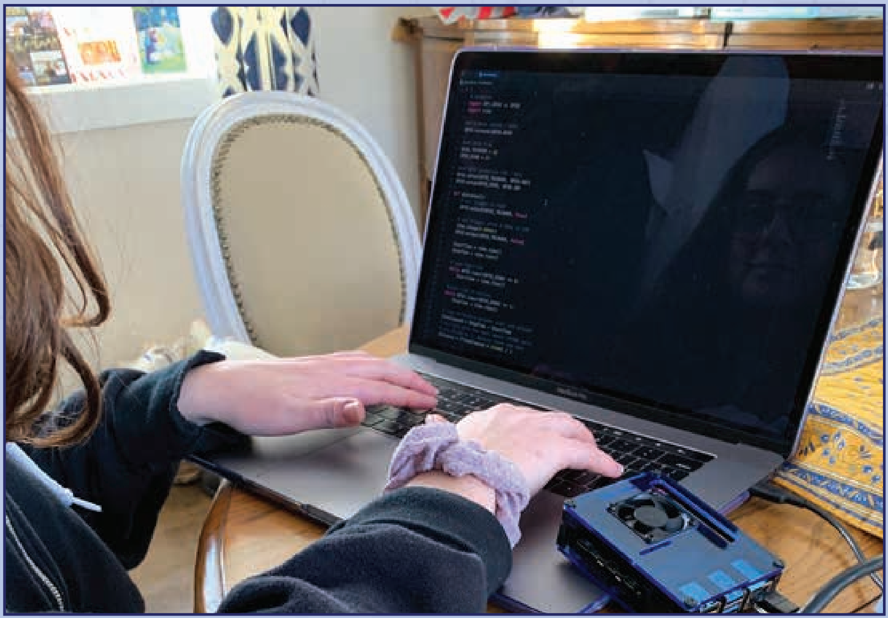
VANDERBILT UNIVERSITY

Low frequency broadband sonar has been used for decades in towed arrays and more recently in Autonomous Underwater Vehicles to find underwater targets. These systems work up to ranges in the low hundreds of kHz and can image over relatively long distances, but image resolution is limited. Higher frequency diver-operated sonar systems have also been developed. These, generally operating near 2 MHz, are intended to image out to about 10 meters, allow 2D tomographic visualization of their immediate surroundings, and have significantly higher resolution.

Recent wars have seen rapid IED and Counter-IED technology developments. The same thing could happen in the underwater space with underwater targets. It would be advantageous to have much higher resolution image data to identify underwater targets.

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

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



Student programming Raspberry Pi to control a remote control car acting as a surrogate for an autonomous underwater vehicle.

NSWC Philadelphia

Networked Multi-Converter Power System: Instrumentation and Measurement

Professor:
Dr. Karen Miu Miller,
Dr. Jaudelice de Oliveira

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

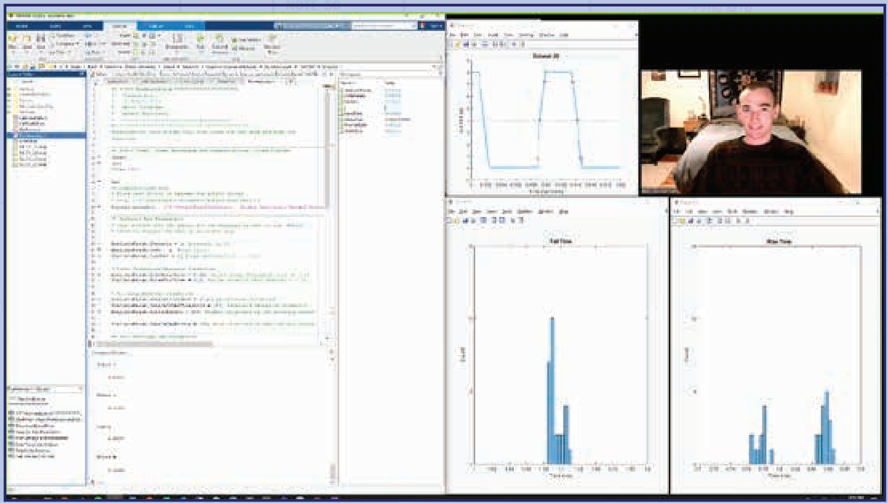
Laboratory testing of the AC/DC microgrid, one-rack setup where different combinations of types and amounts of controllable loads are varied and subsequent actuation delays are captured. Platform and repeatable test procedures were developed by graduate students.

Drexel University

Drexel University and the Center for Electric Power Engineering are creating software and hardware experiments for studying information-embedded power systems, also known as cyber-physical power systems. The modernization of electric shipboard power systems to include power electronic drive and power electronic control is necessary and a promising improvement with respect to energy efficiency and control automation. These enabling technologies are interconnected and networked both in data and in electric power. However, the quantification of improvement requires better understanding of the behavior of power systems with a large number of interconnected converters.

Supervisory control of all-electric shipboard power systems is directly dependent on the underlying instrumentation and measurement systems. When we operate electronic power distribution systems, we expect the advanced technology to improve operations, but we need to quantify the improvement and the limits. This open challenge is cross-cutting for both (1) terrestrial distribution systems, which are installing large numbers of inverter-connected distributed energy resources such as photovoltaics and energy storage with varied levels of communication and control, and (2) naval shipboard power systems as they move toward all-electric drives, zonal AC/DC power distribution, and emerging high-electric energy weapon systems.

The period 3 effort has continued to focus on understanding communication system delay characteristics and multiple converter control actuation characteristics in multi-node power systems. Software simulations of communication delay patterns were conducted under varying packet sizes and sending rates using common types of power system data. Additional AC/DC microgrid hardware experiments were conducted to observe and quantify control actuation times as well as capture uncertainty in actuation start times for static and dynamic loads. It is shown that, even when utilizing multiple, power electronic loads of the same type and manufacturer, measurable differences in control actuation times are experienced. Finally, state estimation techniques, which embed asynchronous communication delays, have been developed and will be implemented in the final period. In this manner, the system impacts of multi-converter communication and control can be evaluated from a function/task operations viewpoint. Hence, the interplay of measurement data and control data must be considered and properly designed for naval shipboard power systems.



Data analysis software program for automated processing and visualization of hardware results: automatic computation of metrics such as rise and fall times, actuation times, etc. Ongoing application of the software program to compile and analyze results.

NSWC Philadelphia

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

Professor:
Dr. Vikas Tomar

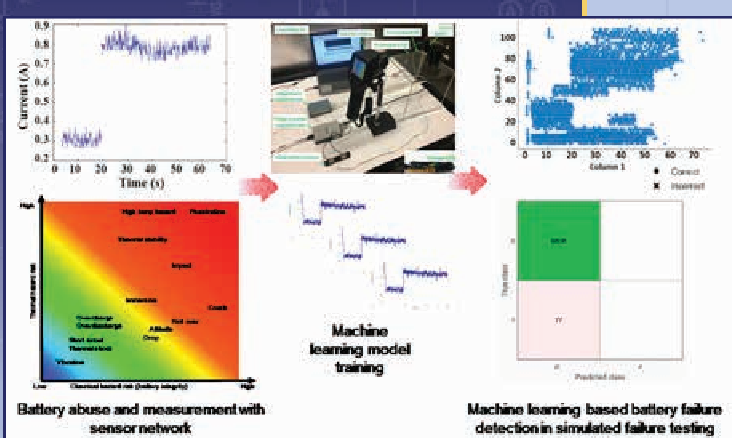
Students:
- Master's: 1
- PhD: 1

Purdue University

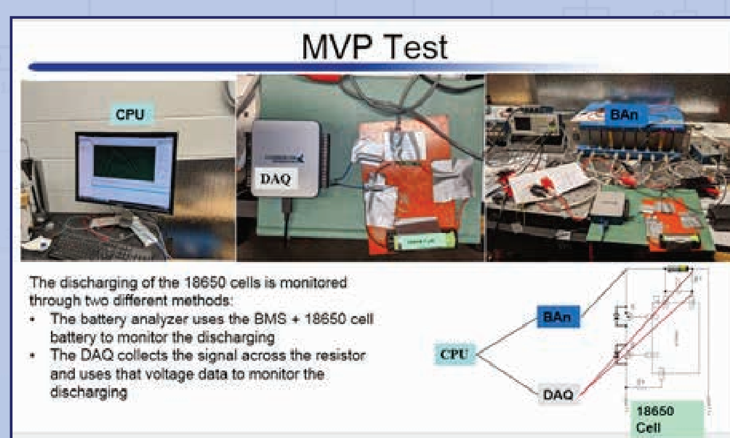
The proposed work will deliver an intelligent autonomous battery management system (SBMS) prototype that is agnostic to the type of vendor supplied lithium-ion (Li-ion) battery pack. The SBMS has the following features:

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

The first 3 years of the proposed work will focus on delivering the solutions for the case of commercial 12-VDC Li-ion battery packs,with the emphasis on the first three bullets above. The overlay SBMS will be applied to commercial 12-VDC Li-ion batteries from three different vendors with proprietary BMS systems, and the algorithms and proof of concept of an autonomous management system overlaid will be proven at scale. Once scalability and usability are established with demonstrated prototypes, the next phase will focus on Navy-specific energy storage system requirements such as the PP-8498 portable charger.



Intelligent BMS development framework at Purdue University.



MVP Test Demonstrated in a review meeting.

NSWC Philadelphia

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

Professor:
Wei Xue,
Robert Krchnavek

Students:
- **Undergraduate:** 45
- **Master's:** 5

Students setting up instrumentation for the NEEC project.

Rowan University

The research objective of the NEEC project at Rowan University is to investigate advanced dielectric materials that can be used in cryogenic superconducting systems on Navy ships. Traditional insulators have limited capabilities for low-temperature applications, due to their inherent material properties in the cryogenic environment. The materials under investigation in this project are polymer nanocomposites designed for gas helium cooled high-temperature superconductor (HTS) cables. The new materials will match the thermal behavior of the cable core element, typically copper, while maintaining high dielectric strength. Polymers and insulating nanoparticles are used to ensure the overall dielectric strength of the composites; their thermal properties are selected to create a compensation effect that results in composites with reduced thermal expansion coefficients.

Our results on polyimide-silicon dioxide nanocomposites show that they have outstanding dielectric strength at cryogenic temperatures down to 92 K. Currently we are exploring various types of nanocomposites and different coating methods of dielectric films on thin wires. In addition, our team is designing and building an in-house cryogenic circulation system that will allow us to perform electrical and thermal testing on materials in a cryogenic environment. These new dielectrics will provide critical benefits such as wider temperature windows, additional design flexibility, higher current density, and large power capacity for a variety of applied superconductor systems.

The NEEC project at Rowan University has strong student participation at both the graduate and undergraduate levels. Since the beginning of the project in 2017, Rowan's NEEC project has provided substantial research work for 5 graduate students and 45 undergraduate students. These students have received extensive training on Navy-relevant skills such as materials research, design, manufacturing, testing, and failure analysis. The research activities and hands-on experience from this project has prepared them for Navy-related jobs, with a number of students being employed by the Navy.

NEEC students working on their NEEC project.

NSWC Philadelphia

A Computationally Efficient Distributed Shipboard Condition Prognostics System

Professor:
Bin Zhang,
Paul Ziehl

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

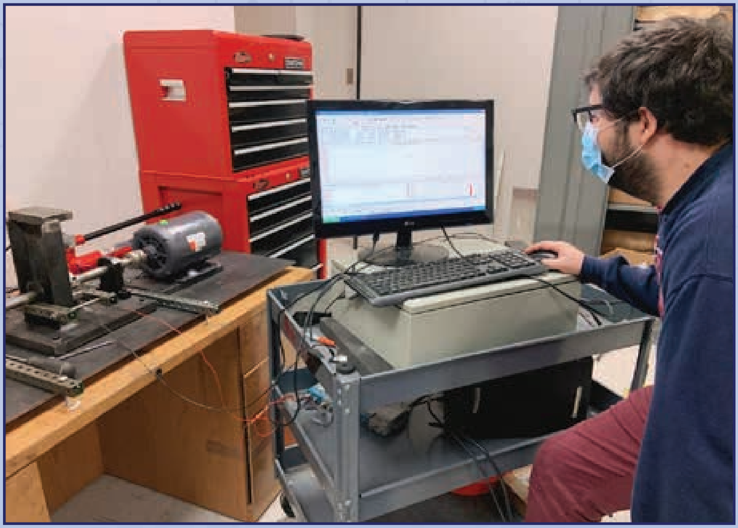
University of South Carolina

Condition-based maintenance (CBM) adopts a paradigm shift for maintenance of complex machines and large-scale assets to ensure Navy mission safety and success. Fault diagnosis and prognosis (FDP) and nondestructive evaluation/structural health monitoring (NDE/SHM) are fundamental enabling technologies for CBM. In this effort, the University of South Carolina (USC) developed a low-cost distributed shipboard condition prognostics system (SCPS) to reduce operation and maintenance (O&M) cost and assure critical Navy mission accomplishment.

The distributed SCPS is designed to deal with common faults from some critical components. The target components include bearings and critical circuits. The research work includes data analysis, fault dynamics modeling, and new algorithm development, in which different types of machine learning and deep learning approaches (deep belief network, convolutional neural network) and Bayesian estimation and prediction approaches (particle filter, extended Kalman filter) were developed. Moreover, they are integrated in a novel Lebesgue sampling framework to enable the deployment on local hardware for distributed applications. Bearing and circuit test benches have been developed in this work for verification and validation.

The project team is also working on the understanding of mechanical degradation through the analysis of acoustic emission data gathered during experimental procedures. In this aspect, we are exploring algorithms including b-value analysis, historic index, information entropy, and machine learning approaches including random forest. The results are verified against ground truth obtained from the experimental program. The designed SCPS can meet the growing demands of Navy shipboard machinery systems in aspects of economy, optimality, reliability, and safety.

NEEC students setting up equipment.



NEEC student analyzing data.

NSWC Port Hueneme

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

Professor:
Dr. Rahul Rai

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

Evaluating NEEC results.

NEEC Team.

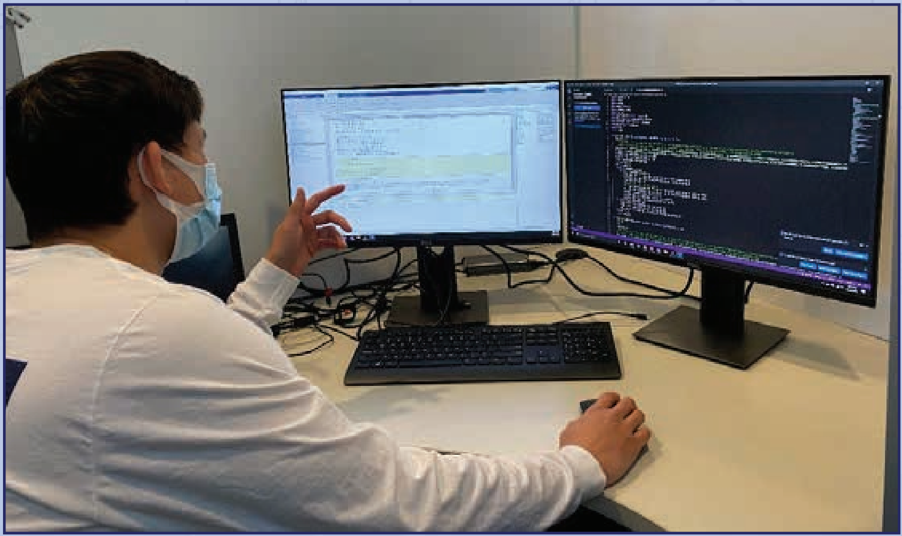
Clemson University International Center for Automotive Research

University at Buffalo, The State University of New York

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

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

The proposed project also provides an excellent opportunity to engage graduate and undergraduate students in a Navy-related research problem and expose them to open-ended, hands-on projects that are more effective in promoting experiential learning. The research focus is well aligned with the PH-01 NEEC topic area and will encourage students to consider exciting career opportunities associated with the U.S. Naval Enterprise.



Analyzing NEEC data.

NSWC Port Hueneme

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

Professor:
Tobias Höllerer

Students:
- Undergraduate: 8
- PhD: 4

University of California, Santa Barbara

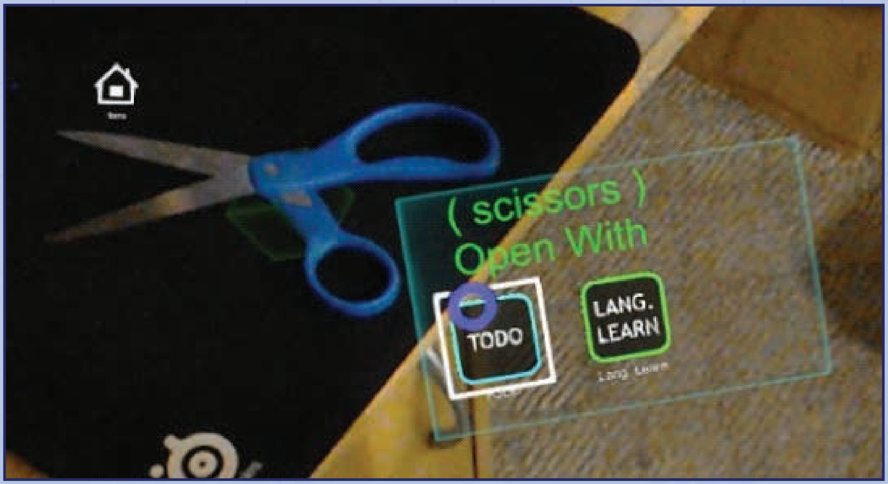
UC SANTA BARBARA

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

This effort contributes basic research towards new capabilities that employ computer vision and machine learning technologies to track users with mobile augmented reality (AR) devices robustly and reliably in indoor (water- or land-based deployment and training spaces) or outdoor environments, using only local (hand-held device or body-worn) sensors, and assuming no prior preparation of the environment in which the AR assistance will occur. Our scene modeling, tracking, and registration approach constructs and maintains a hybrid model of a large tracking environment and utilizes machine learning for geometric and semantic modeling of key environment objects.

The team has made significant progress on three fronts: (1) scene reconstruction from SfM/SLAM and AR camera feeds via novel deep learning architectures, (2) interior scene understanding via machine learning, and (3) UI demonstration and evaluation for task switching during AR maintenance (using the HoloLens 2).

We have involved and mentored undergraduate researchers and high-school research interns right from the beginning of this effort, and these activities have resulted in three poster presentations at top-tier professional conferences (AAAI Student Abstracts 2020 and 2021, plus the Association for Computing Machinery (ACM) International Conference on Multimodal Interaction (ICMI)) and a full paper submission to the Conference on Computer Vision and Pattern Recognition (CVPR) with the high-school mentees as lead authors.



Mobile augmented reality interface for context-based task switching in maintenance scenarios (using HoloLens 2).

NSWC Port Hueneme

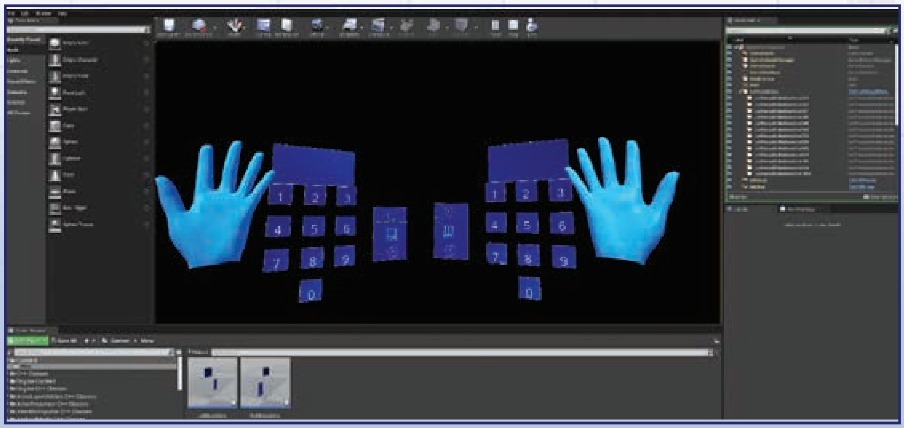
Augmented Reality-Assisted Maintenance Operations of Underway Replenishment System (URS)

Professor:
Aaron Elkins,
Bongsik Shin

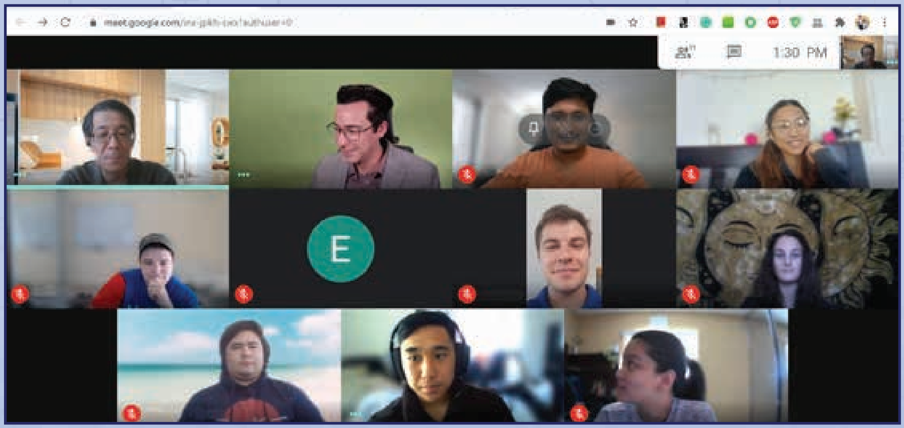
Students:
- **Undergraduate:** 5
- **Master's:** 1

San Diego State University

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



Right- and left-handed user HandMenus for inputting error codes while using a Hololens 2 device.



Faculty and students engaged in a weekly research meeting.

NEEC

Naval Engineering Education Consortium

Michigan Technological University 1885

PennState

Vanderbilt University

The University of Tennessee Knoxville

LSU

Florida State University 1851

The University of Rhode Island

West Virginia University

CU-ICAR Clemson University International Center for Automotive Research

M University of Michigan

University of Maryland

UF University of Florida

IOWA

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Purdue University

San Diego State University

FAU Florida Atlantic University

Drexel University

South Dakota Mines
An engineering, science and technology university

ASU Arizona State University

University of New Hampshire

Virginia Tech

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University of Washington

University of South Carolina
College of Education

Johns Hopkins University

Washington State University

UC Santa Barbara

Brigham Young University BYU Founded 1875 Provo, Utah

UB University at Buffalo

Baylor University

Rowan University

Embry-Riddle Aeronautical University Daytona Beach, Florida

Oregon State University

PNW Purdue University Northwest

Recinto Universitario de Mayagüez CAAM Universidad de Puerto Rico

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