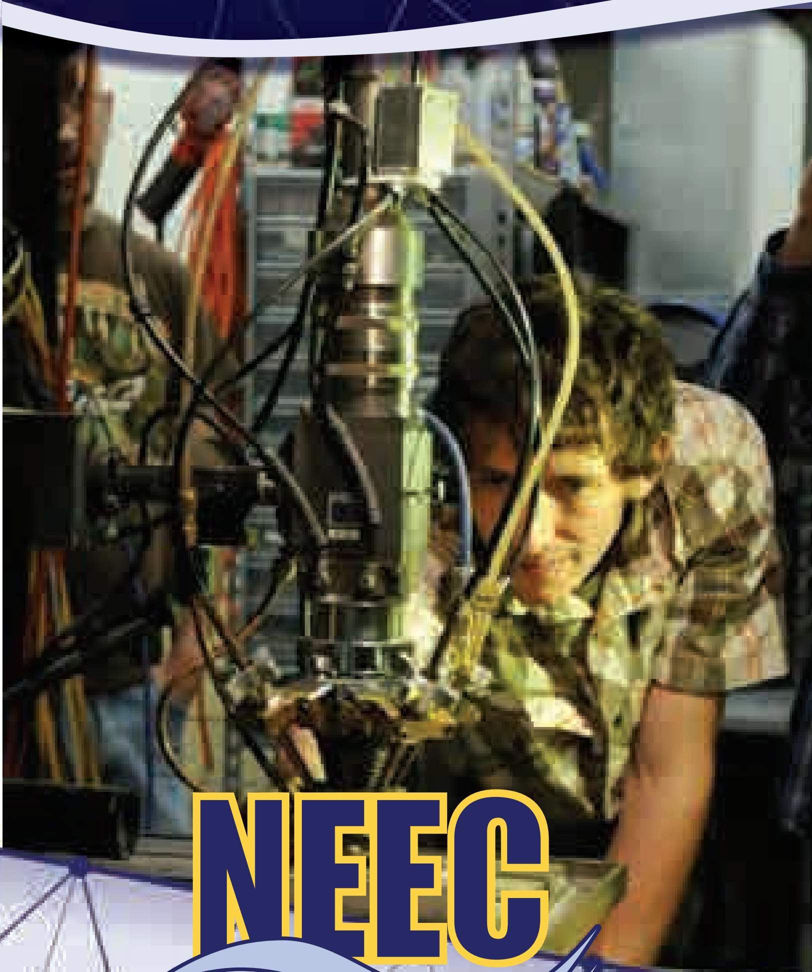
NAVAL ENGINEERING EDUCATION CONSORTIUM PROCEEDINGS

2020



NEEC
NAVAL ENGINEERING EDUCATION CONSORTIUM

20-NUWC-GRA/0178

Message from the Executive Director

I would like to welcome you to the third annual Proceedings of the Naval Engineering Education Consortium (NEEC). This NEEC Proceedings captures the 2019 highlights of our NEEC activities by documenting the research projects to date and describing ongoing and future projects.

The NEEC program is important for the hiring, development, maintenance and sustainment of the technical knowledge base that is crucial to the execution of our undersea and surface warfare missions, which are critical to the Navy and the nation.

The NAVSEA NEEC program aligns well with the new 2020-24 NAVSEA Warfare Centers Strategic Plan, whose vision is "Accelerate Maritime Superiority – Today, Tomorrow and the Navy After Next." The goals defined in the plan—Empower the Workforce, Technical and Business Excellence, Enhanced Partnerships, and Relevant Innovation—are directly applicable to the NEEC program.

Empower the Workforce: With over 50 grants awarded to U.S. universities, the NEEC program continues to seek and hire talented students in critical and specialized fields, which are particularly important in this world of rapidly changing technology. In 2019 we saw former NEEC students excelling as NAVSEA employees and being recognized as the New Hire of the Year, Cybersecurity Red Team Lead, and Principal Investigators sponsored by the Office of Naval Research.

Technical and Business Excellence: We have improved the business process, and going forward, NEEC awards will all be grants (no labor intensive contracts). The technical NEEC research projects are explicitly aimed at current Navy priorities. The projects address important technological challenges in Navy domains from the seabed to space—from materiel to information.

Enhanced Partnerships: The NEEC program works collaboratively across all the 10 WC divisions. The program takes advantage of Navy internships, such as the Naval Research Enterprise Intern Program (NREIP), to encourage NEEC students to work at one of the divisions during the summer. We want to know if it is a good fit for both the student and the division (or perhaps a different command). The goal is to hire and retain highly motivated NEEC students at each WC division. We also seek to expand the number of universities exposed to the Navy's problems and conducting research for us.

Relevant Innovation: The NEEC universities are working on cutting-edge technologies, such as quantum science, AI/machine learning proficiency, and material science knowledge. As the WCs look for sources of great ideas for the most effective products and services for our Navy, there is no better place than America's exceptional universities.

This NEEC Proceedings portrays a broad team effort, and I would like to recognize the people that make NEEC successful: the university professors and students, the scientists and engineers, the mentors, Government grants officers, and the NEEC Directors at the NAVSEA Warfare Centers.

Sincerely,
Brett Seidle, Ph.D.
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 complex interrelated systems for the Naval and Defense acquisition communities.

We have had a successful year as we continue to grow the program, with over 50 grants awarded to U.S. universities. In 2019, eight of those grants were awarded with sponsor-directed funding. As NAVSEA continues to invest its own internal funding to support this excellent program, we are now seeing strong gains in direct program sponsorship, as our Navy sponsors see the benefits in participating in the program.

NEEC engages in project-based research within academia that targets the Navy's technology needs, acquired or developed in-house, and cultivates a future science and engineering workforce. Through NEEC, the Navy funds research and development projects at academic institutions to actively engage professors and their students to work alongside knowledgeable personnel familiar with the Navy's technology challenges.

Participating students must be U.S. citizens and should be motivated to seek employment within NAVSEA or a sponsoring Navy command upon graduation. Select Navy personnel, acting as mentors, work in partnership with professors to identify those students interested in Navy civilian service. As opportunities arise, students are alerted to internships at Navy Warfare Centers that are designed to help them grow their potential to become part of the Navy's science and engineering workforce.

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.

The NEEC team is looking 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

University Partners

Arizona State University
Baylor University
Boston University
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Florida State University
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University of Tennessee
University of Texas at Arlington
University of Virginia
University of Washington
University System of New Hampshire
Vanderbilt University
Virginia Polytechnic Institute and State University
Washington State University

NSWC Carderock

High Resolution Quantification of Turbulent Boundary Layer Flows Along Biofilms and Their Associated Drag

Professor: Dr. Steve Ceccio

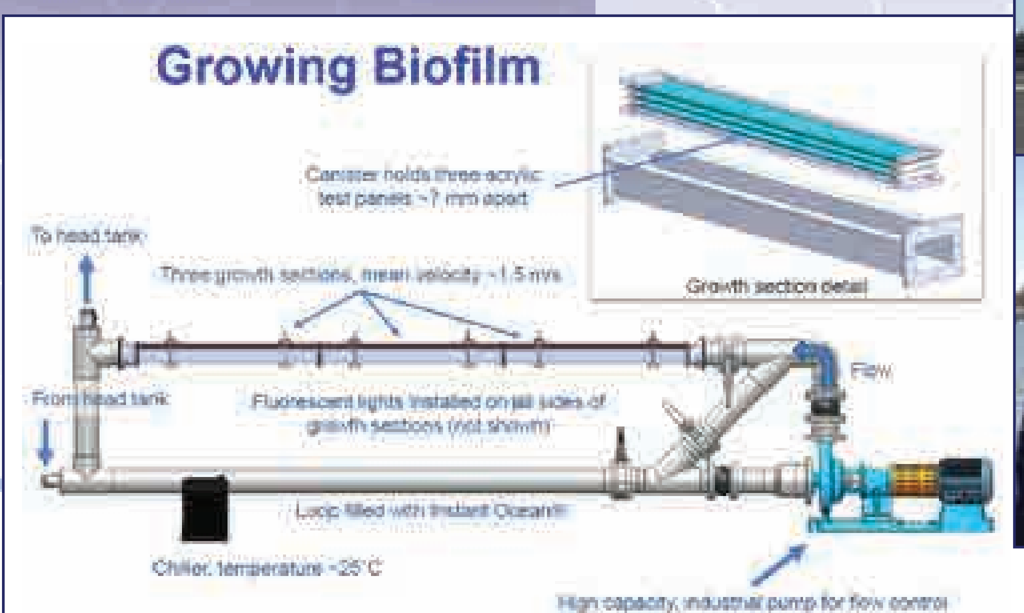
Technical Capability Alignment: CD03 Ship and Submarine Systems Concepts, Technologies, and Processes

University of Michigan

The objective is to measure and understand the drag producing mechanisms of biofilms. Biofilms are the soft growth that first occurs on ship hulls and that is responsible for a surprisingly large drag penalty. Drag is being measured in a channel flow and converted to terms that can be used in computational fluid dynamics roughness models. The physics of the drag producing mechanisms are being studied using Particle Image Velocimetry (PIV).

Soft biofilm for this study was cultivated on smooth, acrylic test surfaces in a custom-built growth loop housed in the Marine Hydrodynamics Laboratory (MHL) at the University of Michigan. Flow control was provided by a large industrial pump, a chiller maintained the loop at 25°C, and fluorescent lights surrounding the growth sections (not shown) provided illumination. The length of each growth section is a little over a meter. After a period of growth development, the hydrodynamic performance was evaluated for panels covered in live fouling, and rigid replicas of select biofilm were generated from a laser scanner point cloud via 3D printing.

Students visiting Naval assets and Washington, DC, in support of their NEEC efforts.



Rendering of the biofilm growth loop.

NSWC Carderock

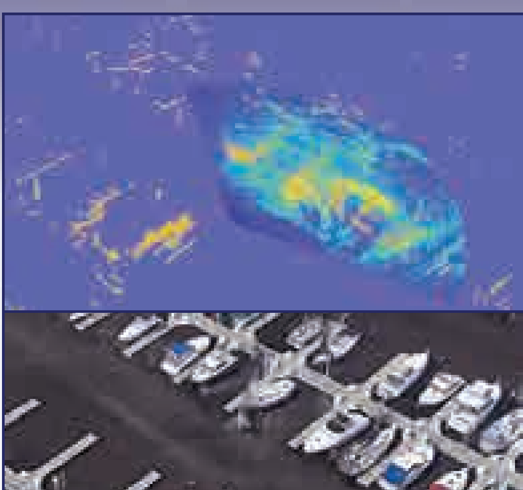
Robust Multi-Domain Situational Awareness Through Sensor Fusion

Professor: Dr. Eric J. Coyle

Technical Capability Alignment: CD06 Unmanned Vehicles Naval Architecture and Marine Engineering

Embry-Riddle Aeronautical University

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. This research investigates methods of representing, fusing and processing perception data collected from multi-domain unmanned assets. The traditional approach to sensor fusion uses multiple measurements or related quantities using tools, such as a Kalman filter, to provide more robust measurements and state estimates. However, in the context of object detection and classification, this approach breaks down because different sensing modalities measure unrelated or ambiguously related quantities, such as an object's spatial characteristics, visual characteristics, and state. To address this issue, this research investigates the use of common forms of data representation and tools to fuse multi-modal data. An early example of this approach is USV-collected Lidar and UUV-collected sonar data fused into a single-point-cloud representation. This enables the use of object segmentation and classification algorithms to more robustly detect and classify objects seen by one sensing modality or both. To test fusion techniques, data is time synchronized and logged locally on the unmanned platforms. An offline playback tool is used to replay mission data with accurate timing and to visualize the collected data. This playback system enables direct comparisons between centralized and distributed data processing for both the techniques and testing.



Unfiltered snapshot of a Lidar (yellow points) and sonar (blue and yellow circular sector) point cloud compared to satellite view of the same area on a different day.

NEEC and Maritime RobotX Challenge students and faculty after a successful day of testing.

NSWC Carderock

Integrated Simulation and Testing for the Qualification of Composite Parts Fabricated Through Additive Manufacturing

Professor: Dr. Stephanie TerMaath

Technical Capability Alignment: CD03 Ship and Submarine Systems Concepts, Technologies, and Processes

NEEC students with 3D printed test coupons.

University of Tennessee, Knoxville

The project objective was to explore and demonstrate the potential of an integrated experimental and computational approach to the qualification process of additive manufacturing (AM) composite materials fabricated with embedded fibers. AM provides the capability to rapidly design and produce parts as needed to reduce a ship's downtime and improve maintainability at sea. This project demonstrated a comprehensive approach encompassing computational simulation, AM demonstration, and experimental testing to investigate the feasibility of an integrated building block approach for the qualification of chopped fiber-reinforced composites fabricated with fusion deposition modeling. Phase 1 demonstrated this approach at the coupon level to predict stiffness and strength, identify the most important manufacturing parameters for repeatability, and minimize variation in mechanical properties. Phase 2 efforts focused on crack growth investigation and demonstration of a representative Navy part using both desktop printers and Big Area Additive Manufacturing (BAAM).

Phase 3 efforts used computational modeling to correlate the process from the microstructure to macrostructural properties.

Ph.D. candidate at UTK with NSWCCD mentors visiting the Oak Ridge Laboratory.

NSWC Carderock

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

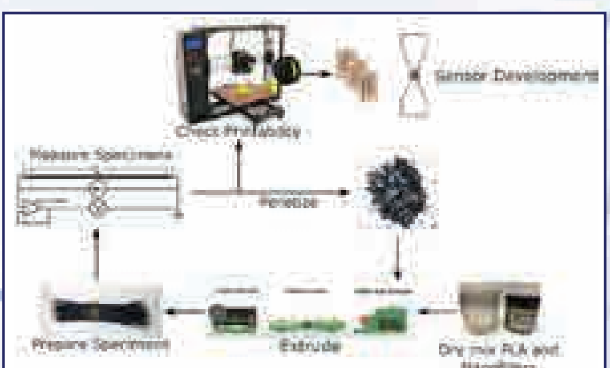
Professor:
Dr. Jose Garcia-Bravo (Lead),
Dr. Brittany Newell (Co-Lead),
and Dr. Tyler Tallman (Co-Lead)

Technical Capability Alignment:
CD03 Ship and Submarine Systems Concepts, Technologies, and Processes

Purdue University

Multifunctional additive manufacturing (AM) has immense potential to create embedded sensors or actuators for the structural health monitoring (SHM) of vessels, equipment, and other critical applications. The focus of this project is the production of materials and processes for the creation of sensors and actuators using nanofiller-modified fused deposition modeling (FDM) AM. This will allow for the production of cost-effective, in-house, and highly customizable/application-specific sensing technology for SHM. Our goals are (1) to identify methodologies to produce electrically and magnetically capable materials compatible with existing and available standard 3D printers and (2) to design and create devices that can be used as sensors and actuators for health and condition monitoring. The materials and process established for creating these sensors are also tested and benchmarked against traditional sensing elements. Using a rigorous design of experiments (DOE) methodology, the Purdue team has been able to experimentally identify optimal production conditions for the creation of a carbon nanofiller-modified filament specially tuned for the manufacturing of piezoresistive-based strain sensors. The process developed by the Purdue team produces a polymeric filament that is ready to be used in conventional FDM printers for manufacturing 3D printed sensors. The Purdue team has also led an initiative to increase student usage and knowledge of AM technology through a 3D Printathon Challenge. In November of 2019 the inaugural 3D Printathon Challenge was launched, and a group of students competed in teams to develop compressed air-powered FDM-printed engines. This will be an annual competition.

Dr. Waters with Purdue Professors Tallman, Newell, Garcia-Bravo and the 2019 3D Printathon Challenge winners. Top left corner: 3D printed engine prototypes.



Flowchart summarizing work on multifunctional AM sensors. Actual test specimen shown in the box.

Students mixing nanofillers and PLA for filament production.

NSWC Carderock

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

Professor: Dr. Stephen Licht

Technical Capability Alignment: CD06 Unmanned Vehicles, Naval Architecture and Marine Engineering

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 broaching. Control problems are especially acute when operating at slow speeds, as dive planes and rudders require forward speed to maintain control authority.

The technical goals of this effort are to develop adaptive depth control strategies for overactuated underwater vehicles in stratified flow and to characterize the nonlinear depth dynamics of cross-body internal and external thrusters near the surface. The technical efforts are centered around experiments with unmanned underwater vehicles modified for depth control and thruster dynamics, involving testing in the URI Tow Test Tank.

Researching near surface operations will be important for Navy vessels.

NSWC Carderock

Acoustic Testing and Signal Analysis for Noisy and Complicated Environments

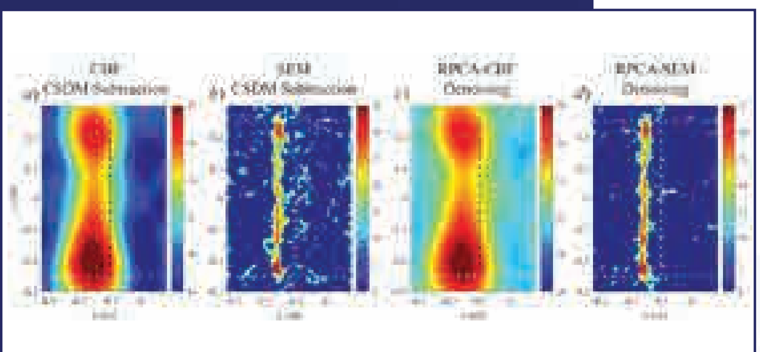
Professor: Dr. David Dowling

Technical Capability Alignment: CD22 Surface and Undersea Vehicle Underwater Signatures, Silencing Systems and Susceptibility

University of Michigan

The University of Michigan (UM) NEEC Acoustic team uses modern simulation and experimental tools to collect acoustic array measurements and investigate signal processing schemes relevant to the U.S. Navy. Here the focus is on the acoustics found in Navy testing environments where noise and reverberation are common but some geometric control of the source and recording locations is possible. Array measurements are commonly made in both air and water by using 16 PCB 130E20 microphones or 16 Reson 4013 hydrophones, respectively. NEEC students are advised by the team leader, but they are always encouraged to work with their student colleagues, plan their own work, collect their own data, program their own acoustic simulations, and write their own data reduction routines. Thus, the UM NEEC Acoustic team provides a "learn-by-doing" experience for students at all levels.

During FY 2019, A total of 11 different students participated on the UM NEEC Acoustic team, and one of these was hired by NSWCCD. The students worked on three project tasks: (1) aeroacoustic noise source quantification using data collected in NSWCCD's Anechoic Flow Facility (AFF), (2) classification of natural transient signals, and (3) remote localization of changes in a vibrating structure. Sample results from each task appear below.



These are signal processing outputs from acoustic array measurements made in the NSWCCD's AFF using conventional beamforming (CBF), the spectral estimation method (SEM), and robust principal component analysis (RPCA). The images show the plane of a flat test surface on which a turbulent boundary formed with the flow moving from left to right. The noise source of interest was a gap in the plate surface (marked by a dashed line). The signal processing was done in a 5-to11-kHz bandwidth. Except for the offset of several centimeters, which is most likely an experimental artifact, the techniques illustrated here were able to localize the slot as a noise source. The techniques involving an extra computational optimization (those that include SEM) provide superior spatial resolution.

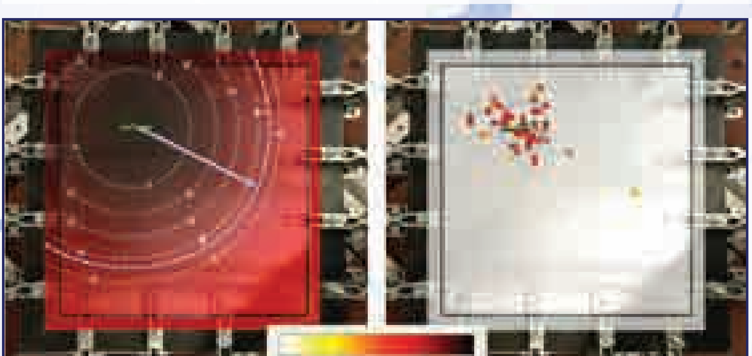
Classification results for five different natural transient sounds: metal-to-metal impact, plastic-to-plastic impact, a balloon pop, human hand clapping, and wood-to-wood impact. Using a variety of features, four of the five transient sounds could be classified. However, human hand clapping was classified as "plastic" or "wood" impact in half of the trials. This classification performance is comparable to that from human listening to the same sounds.

K=3

Current Classification Result

Confusion Matrix

Data Class \ Predicted Class	Metal	Plastic	Balloon	Clap	Wood	True Positive
Metal	12	0	0	0	0	100%
Plastic	0	12	0	0	0	100%
Balloon	0	0	11	1	0	91.7%
Clap	0	0	1	6	5	50%
Wood	0	0	0	0	12	100%



These are signal processing outputs from acoustic array measurements of a vibrating square plate with clamped edges that has synthetic damage projected back on the plate. The synthetic damage is a small through cut and is marked by the green line segment in the images. The panel on the left shows results from conventional beamforming with background subtraction. The panel on the right shows results from the same array for the spectral estimation method with coherent background removal (SEMCBR), a new technique developed for this NEEC project. The purple dashed circle is the uncertainty region for localization of the through cut. Although both techniques localize the through cut, the resolution of SEMCBR is much better.

NSWC Corona

High-Performance Post-Quantum Cryptography

Professor:
Dr. Reza Azarderakhsh

Technical Capability Alignment:
AC02 Quality and Mission Assurance Assessment

Florida Atlantic University

To support the Navy's need to stay aware of emerging technical challenges, Florida Atlantic University (FAU) is providing valuable research on the topic of "High-Performance Post-Quantum Cryptography." Quantum computers will be able to break our current security as soon as they become available. Although there is no cryptographically relevant quantum computer yet, we need to be prudent and take action now to prevent losing our secrecy going forward. There are states and agencies currently storing encrypted data that will someday be vulnerable to attack.

As FAU finished the first semester on this project, the team's efforts were aimed at (1) designing and developing quantum-safe cryptographic algorithms and architectures based on hard mathematical problems like maps on elliptic curves and (2) investigating the feasibility of using these algorithms and architectures in embedded and resource-constrained devices. More specifically, this project provides a hardware/software co-design approach to performing the computations as well as providing the protocols for a quantum-safe key exchange mechanism submitted to the National Institute of Standards and Technology for further evaluation and standardization.


Students with Dr. Reza Azarderakhsh.

Dr. Reza Azarderakhsh and Dr. Benny Cheng.

NSWC Corona

Metrology & Calibration (METCAL) for Additive Manufacturing (AM)/3D Printing Technologies

Professor: Dr. Rob Candler

Technical Capability Alignment:
AC03 Metrology, Test, and Monitoring Systems Assessment

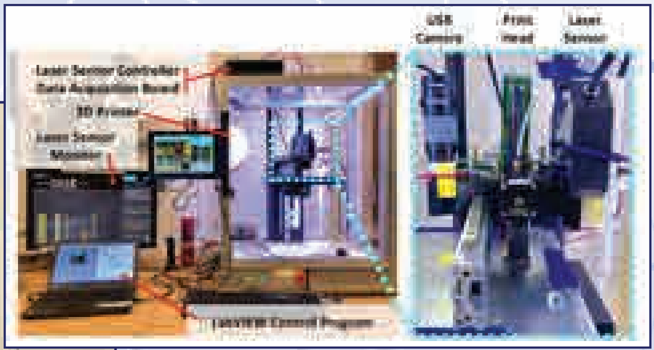
University of California, Los Angeles

The University of California at Los Angeles (UCLA) is researching the topic of "Metrology & Calibration (METCAL) for Additive Manufacturing (AM)/3D Printing Technologies." Research has shown that additive manufacturing is rapidly moving from a system for prototyping and visualization toward a versatile, cost-effective method for low volume manufacturing. To be fully adopted, the Navy needs systems that can perform metrology on the internal and external geometry of printed structures to ensure that they are within specifications.

Since 2017, NSWC Corona Division has been working on a Naval Engineering Education Consortium (NEEC) research project for additive manufacturing and 3D printing technologies at UCLA. The goal is to create and demonstrate a method for constantly recalibrating additive manufacturing, including functional materials, on a layer-by-layer basis. This will enable validation of the manufactured part and will improve part tolerances based on new sensors and feedback control.

The UCLA students and faculty use a high-precision laser-scanning sensor to reconstruct a layer-by-layer model of printed structures with a 3D printer. The scanned information qualifies the geometry during manufacturing and eventually will allow in situ corrections to print errors. Additional work includes investigation of machine learning based on design geometry for classifying and predicting defects. The desired end result is improved resolution of 3D printed parts and validation of their geometry at the time of manufacture.

Leading the project is UCLA Principal Investigator and Professor Rob Candler, a National Defense Science and Engineering Graduate (NDSEG) Fellow and an advocate for the NEEC program. He has mentored several students who have worked on the current NEEC project. He also works with students in the Fast Track program and encourages entry-level students to apply for the Naval Research Engineering Internship Program (NREIP) internships, supporting the education recruitment component of NEEC.



The system setup consists of a 3D printer, a laser sensor, and data acquisition devices.

UCLA and NEEC collaborators are pictured with a custom layer-by-layer metrology tool. From left to right: two NEEC-funded UCLA graduate students with Matthew Khalil, NISE Portfolio Manager, NSWC Corona, and UCLA Professor Rob Candler.

NSWC Corona

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

Professor:
Dr. Vagelis Papalexakis

Technical Capability Alignment:
AC02 Quality and Mission Assurance Assessment

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 is 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 work of the team has focused on streaming data and has developed techniques that adapt to large amounts of incoming data accurately and at a fraction of the complexity of other competing approaches. Furthermore, the team was the first to introduce the notion of "concept drift" in this scenario, where the incoming stream of data is "drifting" from what is considered already known and "normal." A technique was proposed that is able to detect it and adapt to such "drift," whereas existing methods fail. Their work has appeared in prestigious data science venues including ACM KDD, SIAM SDM, and ECML-PKDD, IEEE/ACM ASONAM, and ACM CIKM.

Research results have been featured in a variety of invited and conference presentations. In addition, the research conducted by the Principal Investigator and the research team has resulted in five publications in top-tier peer-reviewed venues at the end of 2018. More publications were prepared in 2019, which will be reflected in the report for the first half of Year 3.

Dr. Papalexakis and students.

Dr. Papalexakis and Karon Myles, NEEC Director, NSWC Corona, at NEEC Day 2019 (Newport RI).

NSWC Crane

Harnessing Quantum Correlations for Quantum Sensing

Professor: Dr. Ram Narayanan, Dr. Matt Brandsema

Technical Capability Alignment: CR19 Sensors and Surveillance Systems

Pennsylvania State University

Through the NEEC project "Harnessing Quantum Correlations for Quantum Sensing," Penn State University (PSU) has been systematically developing experimental capabilities in the quantum optics laboratory. The graduate students working on the project have contributed significantly in developing the experimental capability and have been instrumental in equipment design and troubleshooting problems. In addition to the experimental work, PSU published two conference papers pertaining to theoretical and simulation-based work. The theoretical calculations result in predictions that define the quantum advantage compared to the classical in regard to correlations used for detection, and the simulation work pertains to modeling the exact experimental setup to get a better sense of how to progress in the experiment.

The NEEC project with PSU has benefited NSWC Crane in several distinctive ways. First, the interaction with PSU's faculty and students has benefited Crane's internal research efforts by providing the necessary technical advice and guidance to generate entangled photons for quantum sensing. Additionally, NSWC Crane selected two student research assistants to spend a summer internship period at NSWC Crane through the ONR NREIP. One of these students will be working alongside NSWC Crane personnel during the development of an onsite entangled photon source. Finally, the development of a sophisticated model by the PSU faculty may also potentially benefit the sensor/radar communities at NSWC Crane.

Future applications may include Navy ship sensors.

NSWC Crane

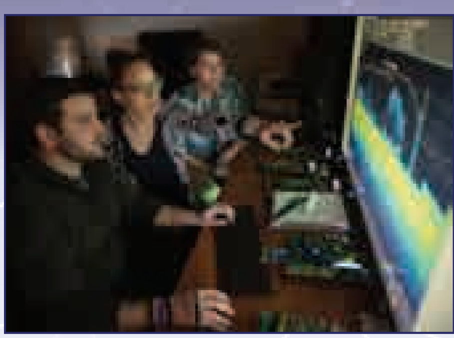
Attacking RF Machine Learning Systems

Professor: Dr. Alan Michaels, Dr. Chris Headley

Technical Capability Alignment: CR04 Electronic Warfare Systems RDT&E/Acquisition/ Life Cycle Support

Virginia Polytechnic Institute and State University

The research engagement made possible through NEEC and the relationship it established between NSWC Crane and the HUME Center for National Security and Technology at Virginia Polytechnic Institute and State University (Virginia Tech) contributed to advancements regarding the fundamental understanding of radio frequency (RF) scientific principles as they apply to wireless communication technology. Recent advancements in radio frequency machine learning (RFML) have demonstrated the use of raw in-phase and quadrature (IQ) samples for multiple spectrum sensing tasks. Yet, deep learning techniques have been shown, in other applications, to be vulnerable to adversarial machine learning (ML) techniques, which seek to craft small perturbations that are added to the input to cause a misclassification. The research performed at Virginia Tech demonstrated the vulnerabilities of RFML systems to adversarial attacks by evaluating multiple example attacks against a raw-IQ deep-learning-based modulation classifier. Virginia Tech Research Professor and Director of the Electronic Systems Lab at the HUME Center for National Security and Technology, Alan Michaels, along with Research Professor and Associate Director of the Electronic Systems Lab, Chris Headley, and their team of 19 undergraduate and graduate students have advanced the fundamental understanding of adversarial evasion attacks in the context of wireless communications. Because of this work and the students' participation in the project, there is a greater awareness of the challenges that must be overcome with respect to wireless communication, especially in military applications. In addition to working on the project at the university lab, the team visited NSWC Crane to gain a better understanding of electronic warfare (EW) fundamentals and the connection of EW to the research projects performed in the university laboratory setting. NEEC was instrumental in providing opportunities for engagement between NSWC Crane scientists and engineers and Virginia Tech students and faculty. The research relationship provided value to the Navy not only because of the scientific discoveries that resulted from the research but also because of the number of Virginia Tech students who have expressed interest in pursuing careers as civilian scientists and engineers at a Navy research and development laboratory.



Virginia Tech students working on the NSWC Crane NEEC Project "Attacking RF Machine Learning Systems."

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NSWC Crane

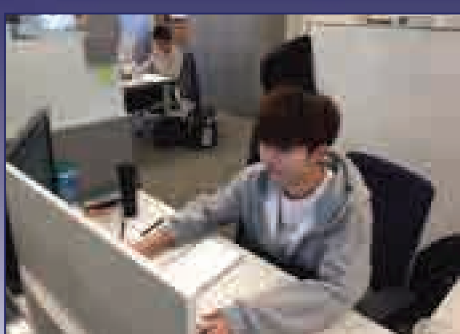
Visualization of Repair Operations Management for Networked Systems Resilience

Professor: Dr. Chenn Zhou, Dr. Bin Chen, John Moreland, Dr. Seokcheon Lee, Dr. Shimon Nof, Dr. Cesare Guariniello

Technical Capability Alignment: CR15 Strategic Systems Hardware

Purdue University

Department of Defense support networks can be very large and interconnected. If there are any failure points within a network, the overall system will be disrupted by any cascading effects. Development of networks with this team's RNSC tool can help plan an efficient way to deal with these failures within the system. By adding a visualization component to the RNSC tool, it will now allow for better views into the system. Showing end users their system network on real-world geographical data gives additional insight that may not be possible with other tools. The goal of this project is to provide a visualization component that will allow users to visualize failure points within critical networks that will in turn provide greater capability for implementing corrective actions and restoring system operation. The team spent this year focusing primarily on developing the necessary software (Visual RNSC 1.0) needed for future research.



Purdue Northwest Students working on the NSWC Crane NEEC Project "Visualization of Repair Operations Management for Networked Systems Resilience."

Purdue Northwest research team and NSWC Crane team at the kickoff meeting for the NEEC Grant "Visualization of Repair Operations Management for Networked Systems Resilience," at the PNW Center for Innovation through Visualization & Simulation (CIVS) Immersive Theater

Purdue Northwest Student working on the NSWC Crane NEEC Project "Visualization of Repair Operations Management for Networked Systems Resilience."

NSWC Crane

Advanced Data Visualizations for Robust Deep Machine Learning

Professor: Dr. David Crandall, Dr. Katy Borner

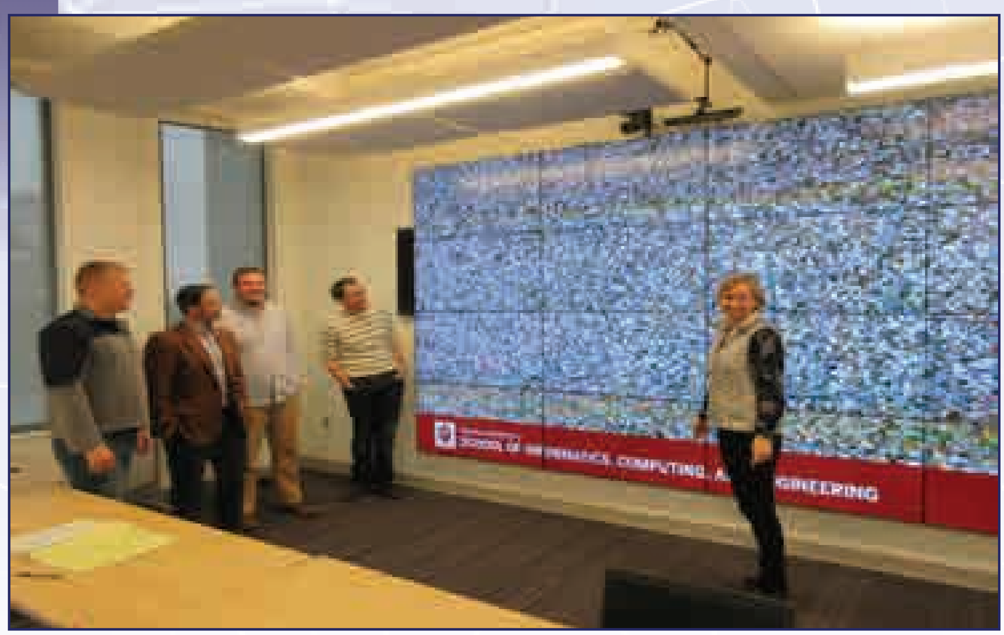
Technical Capability Alignment: CR15 Strategic Systems Hardware

Indiana University

Progress in machine learning has led to impressive advances in artificial intelligence over just the last few years, and computers are now able to outperform humans on a surprising variety of tasks. Amid this excitement, however, are warning signs because machine-learning-based systems routinely make unexpected and unexplainable errors with small noise patterns, imperceptible to humans, that confuse computer vision algorithms. Whether the confusion of the algorithms is accidental or purposefully designed by an adversary, the consequences can be catastrophic in medical, legal, military, and other high-stakes applications. This research project will 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. It addresses four specific challenges: (1) limited training datasets, (2) a lack of explainability and debuggability, (3) adversarial inputs, and (4) a shortage of expertise with machine learning in the workforce. It is expected that this research will lead to a better fundamental understanding of computer vision algorithms, a reduction of errors in artificial intelligence algorithms, and a higher warfighter confidence in the performance of the devices that utilize this technology.

Indiana University student researchers and Research Professor David Crandall (far right) discuss the NSWC Crane NEEC Project "Advanced Data Visualizations for Robust Deep Machine Learning."

Indiana University student researchers and Research Professor David Crandall (far right) working on the NSWC Crane NEEC Project "Advanced Data Visualizations for Robust Deep Machine Learning."



Indiana University Research Professors David Crandall (second from right) and Katy Borner (far right) along with NSWC Crane scientists and engineers discuss challenges in Machine Learning algorithms with respect to image recognition at a quarterly review meeting on the NSWC Crane NEEC Project "Advanced Data Visualizations for Robust Deep Machine Learning."

NSWC Crane

Sensor Fusion for Radar and EO Sensors

Professor: Dr. Yaakov Bar-Shalom, Dr. Peter Willett

Technical Capability Alignment: CR19 Sensors and Surveillance Systems

University of Connecticut

The work performed through this engagement with a NEEC project addresses a technical challenge associated with optical sensors used in target tracking systems. The research performed addresses measurement extraction from optical sensors that blends physics and statistics: the optics' point spread function (PSF), pixel size, dead zone and Poisson/Gaussian observed intensity levels. The research team used a realistic model in which neighboring pixels are separated by a dead zone in the FPA of an optical sensor, and target detection was evaluated to determine if a target exists at the estimated location. The ability to combine sensor data from multiple detection points gives the warfighter an advanced capability by providing real-time data-driven decision technology on the battlefield. As sensors continue to find their way into device applications on the battlefield, it is critical that the warfighter has the capability of evaluating sensor data from multiple sensors in a swift yet accurate manner.

Future applications may include battlefield jamming.

NSWC Crane

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

Professor: Dr. Jinsub Kim, Dr. Raviv Raich

Technical Capability Alignment: CR15 Strategic Systems Hardware

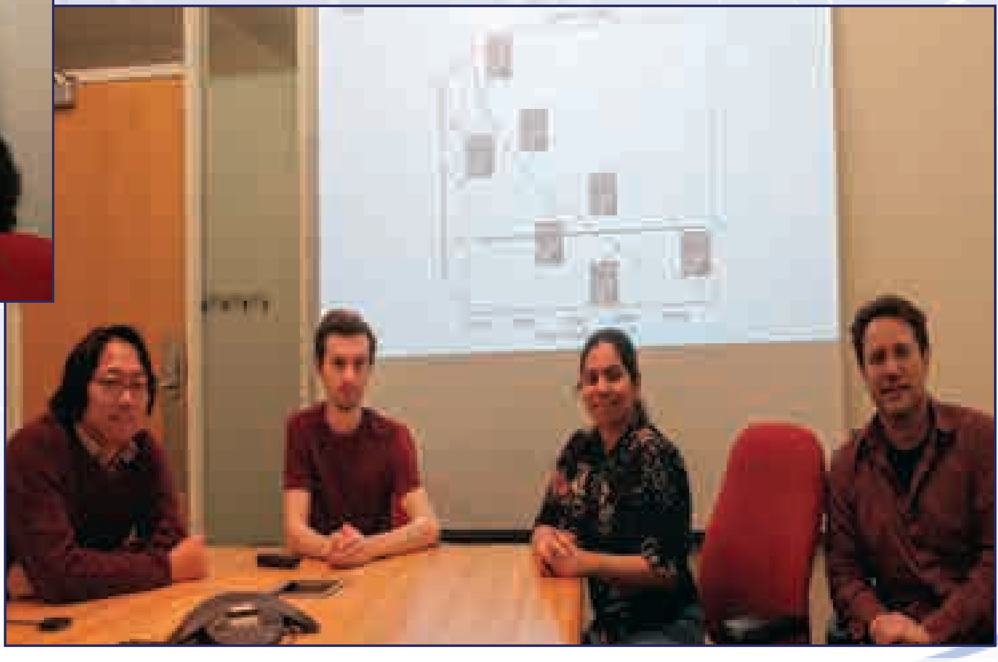
Oregon State University

Machine learning algorithms are popularly used for making statistical decisions (e.g., target detection) about a sensed environment based on various sensor data streams (e.g., vision, acoustic, RF sensors). Such a "sensors-to-decisions" (S2D) system has played crucial roles in various military operations, such as reconnaissance and detection/tracking of enemy units.

The crucial function 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.

The research performed by Oregon State University focuses attention on data attacks wherein an adversary compromises some of the sensors in an S2D system and falsifies data from the compromised sensors to mislead the machine learning algorithm with falsified data inputs and eventually affect its decisions. The groundwork established since this project's inception will lead to important discoveries in future research that will have a long-term impact in expanding the advantage of the warfighter in support of our nation's defense.

Oregon State University student researchers presenting at a review meeting on the NSWC Crane NEEC Project "Cost-Aware Defense of Sensors-to-Decisions System Against Malicious Data Attacks."



Oregon State University Research Professors Jinsub Kim (far left) and Raviv Raich (far right) along with student researchers presenting at a review meeting on the NSWC Crane NEEC Project "Cost-Aware Defense of Sensors-to-Decisions System Against Malicious Data Attacks."

NSWC Dahlgren

Exploration of Additive Manufacturing for Naval Applications in Expeditionary Warfare

Professor: Professor Gene Hou

Technical Capability Alignment: DD05 Surface Combat Systems Engineering and Integration RDT&E

Old Dominion University

The purpose of this project funded by the Naval Engineering Education Consortium (NEEC) is to address concerns about using additive manufacturing techniques onboard ships. Shipboard additive manufacturing is a powerful tool in the fight against component obsolescence. The ability to produce complex parts on demand greatly reduces mission dependency on supply chains threatened by lack of component availability or latency in delivering parts to the Fleet.

Unique shipboard environmental conditions, such as heave, surge, and sway, can cause errors in both modeling and constructing parts. This NEEC effort provides valuable insight into the extent to which these problems occur, as well as some potential mitigation techniques.

One situation studied is the case when the 3D scanner is used to produce the dimensions of the part while its CAD drawing is not available. Old Dominion University (ODU) developed a data average technique that minimizes scanning errors prior to generation of the 3D model needed for additive manufacturing. This research culminated in a published paper:

J. G. Michaeli, M. C. DeGroff, and R. C. Roxas, "Error Aggregation in the Reengineering Process from 3D Scanning to Printing," Scanning, Nov. 2017.

The second situation studied is the effect of the static and dynamic inclination of the printing platform on 3D printing dimensional accuracy. The specific 3D printer studied performs well and maintains a similar level of dimensional accuracy through the testing matrices in both static and dynamic environments. Interestingly, errors introduced when the printer is used at a static inclination angle are not observed in dynamic environments with similar peak angular displacement.

Mounting the Lutzbot Taz 6 on the Reverse Stewart Platform.

NSWC Dahlgren

Quantitative Investigation of the Mechanical Performance and Residual Stress of Additively Manufactured Precipitation Strengthened Stainless Steels

Professor: S. R. Agnew, J. M. Fitz-Gerald

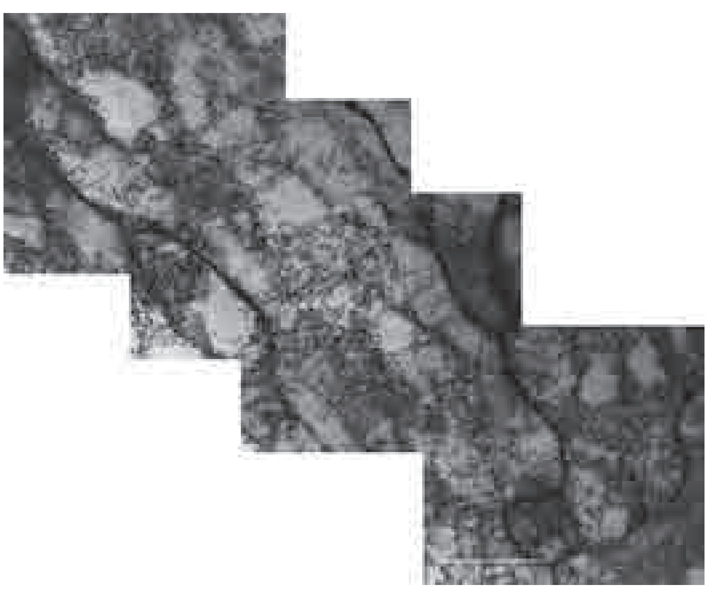
Technical Capability Alignment: DD05 Surface Combat Systems Engineering and Integration RDT&E

University of Virginia

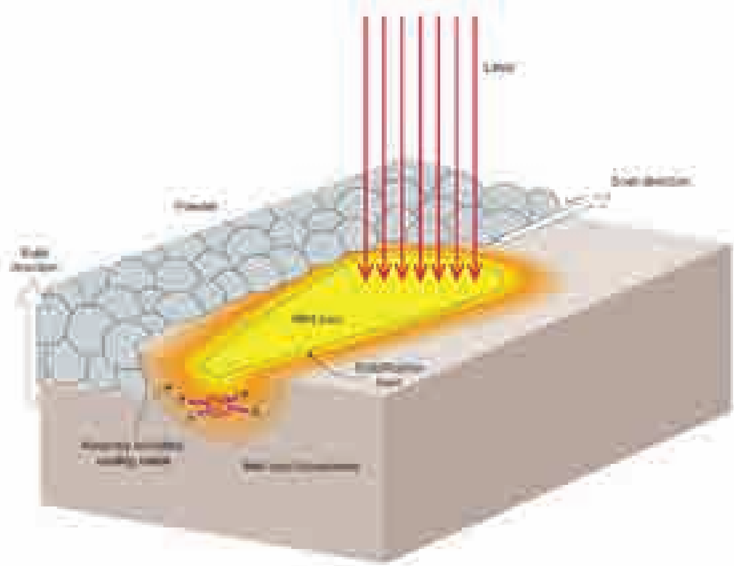
Additive manufacturing provides the U.S. Navy with revolutionary tools for constructing new systems, as well as economically supporting obsolete equipment. Additive manufacturing using plastic has been used since the mid-1980s, and the mechanical behavior of products is well established. More recently, selective laser melting of full-density, heat-treatable metals has created novel possibilities. Unfortunately, many unknowns remain about the mechanical properties of additively manufactured metals. This NEEC grant allowed the University of Virginia to explore the strength, ductility, strain hardening, and anisotropy of additively manufactured 316L stainless steel.

In addition to answering critical questions about selective laser melted stainless steel, this work at the University of Virginia has influenced four graduate students who have gone to work within the Navy research and development enterprise in 2019. One student is now an employee of the Naval Surface Warfare Center's Dahlgren Division, and another has accepted a position at NSWC Carderock. The metrology research has supported one individual who is now a research assistant professor at the U.S. Naval Academy and another who is working on naval products at the steel manufacturer ArcelorMittal.

The steels created through the University of Virginia (UVA) research exhibit both high strength and high ductility. UVA investigated how the unique aspects of selective laser melting contribute to strain hardening. The metrology of selective laser melted steels has revealed information about the detailed solidification microstructure of these materials. Outstanding combinations of material properties appear achievable.



Microstructure of selective laser melted steel.



Schematic depiction of selective laser melting.

NSWC Dahlgren

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

Professor: Sangram Redkar

Technical Capability Alignment: DD20 Chemical, Biological, and Radiological Defense Systems

Arizona State University

A new NEEC grant to Arizona State University, funded by the Defense Threat Reduction Agency (DTRA), 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 of the project, Dr. Prabha Dwivedi of NSWC Dahlgren. 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 (91 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 to the development of novel technologies, from inception to production, and to enhance the DoD workforce with trained and highly capable personnel. With NEEC and DTRA support, the EWD project aims to ensure that the students are acquainted with important DoD research areas, such as warfighter readiness and capabilities enhancement, as well as 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 Ph.D. candidate students in each year of its three-year duration.

Ph.D. student is scanning ear of WMD team member.

From left to right: Dr. Sangram Redkar; Maj. Ryan Morrissey, Deputy Commander 91CST; and Ph.D. candidate.

NSWC Dahlgren

Real-Time Virtualization, Scalable Linux Operating System, and Transactional Memory Middleware for Multicore Hardware

Professor: Binoy Ravindran

Technical Capability Alignment: DD01 Force and Surface Platform Level Warfare Systems Analysis and Modeling

Virginia Polytechnic Institute and State University

The purpose of this project funded by the Naval Engineering Education Consortium (NEEC) is to develop a formal methodology for verifying the security properties of application programs. This work has produced algorithms and software infrastructure that can verify security properties such as memory corruption behaviors of programs written for the x86-64 architecture.

As part of this effort, Virginia Tech developed extensions to the Popcorn Linux compiler, run-time, and operating system infrastructure that can support single instruction/multiple data (SIMD) applications. This work has produced compilation and run-time techniques and their implementations in the Popcorn Linux infrastructure that enable applications with SIMD computational patterns to execute on heterogeneous instruction-set-architecture (ISA) cores and obtain improved performance.

Upgrades to the Popcorn Linux infrastructure include new security extensions. This work has produced compiler, run-time, and operating system techniques that improve the security properties of application programs in, for example, higher entropy against code reuse attacks, data reuse attacks, and input data handling attacks.

Semester-long undergraduate research projects resulted in extensions to the KariosVM real-time virtualization infrastructure and the Hyflow transactional memory infrastructure.

Popcorn Linux, developed with partial support from NEEC, was demonstrated at the Pentagon on June 24, 2016, as part of ONR's 70th anniversary celebrations held at the Pentagon. From left to right: ONR Program Officer Dr. J. Sukarno Mertoguno, ECE Professor Binoy Ravindran, two ECE Ph.D. candidates and NEEC-supported students, ECE Research Assistant Professor Antonio Barbalace, and ONR Program Officer Dr. Ryan Craven. The experimental computer system that ran the first version of Popcorn Linux is in the background.

Virginia Tech's NEEC-supported students working on the Popcorn Linux project, January 2017. The picture in the foreground is that of an experimental computer system that ran the first version of Popcorn Linux.

NSWC Dahlgren

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

Professor: Carey Prieb

Technical Capability Alignment:
DD05 Surface Combat Systems Engineering and Integration RDT&E

Johns Hopkins University

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

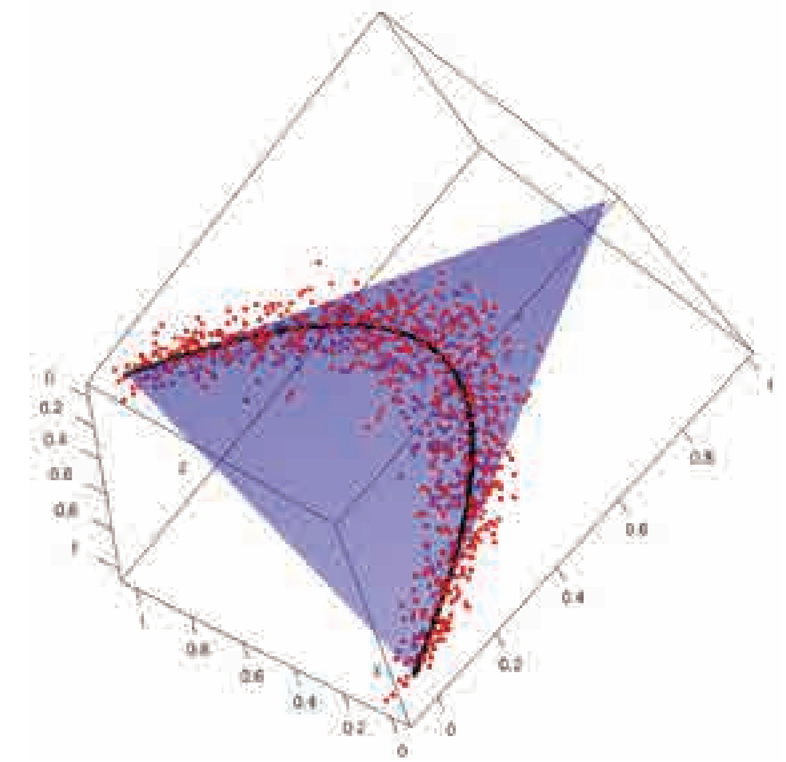
Many modern applications involve data in the form of a network, and the first step in addressing the associated exploitation task is to identify structure in the network, with the endgame being exploitation of discovered structure for subsequent inference. During this NEEC effort, Johns Hopkins University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

Through this effort two associate professors, one assistant professor, and one Ph.D. candidate will gain experience in performing both theoretical and practical exploration of manifold learning as applied to the problems of machine learning as applied to data organized in networks.

Two papers have been accepted for publication:

Michael W. Trosset, Mingyue Gao, Minh Tang, and Carey E. Priebe, "Learning 1-Dimensional Submanifolds for Subsequent Inference on Random Dot Product Graphs," arXiv:2004.07348v2 [stat.ML], https://arxiv.org/abs/2004.07348 .

Avanti Athreya, Minh Tang, Youngser Park, and Carey E. Priebe, "On Estimation and Inference in Latent Structure Random Graphs," arXiv:1806.01401v3 [stat.ME], https://arxiv.org/abs/1806.01401 .



Phase space representation of manifold learning.

Toward Fully Electrically Reconfigurable Communication Systems

Professor: Guoan Wang

Technical Capability Alignment: DD19 Surface Warfare Electromagnetic Environmental Effects

University of South Carolina

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

The 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 that 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.

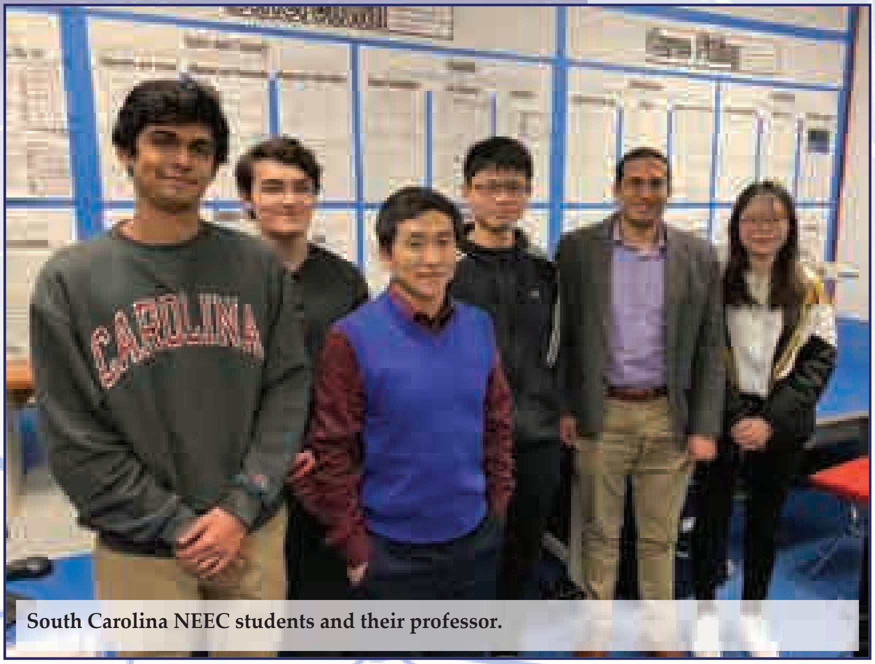
This NEEC effort is providing unique, hands-on experience for one Ph.D. student and two undergraduates. Support from NEEC provides great research and training opportunities for undergraduate students while enabling the development of cutting-edge electromagnetic technologies.

Upcoming publications for this work include:

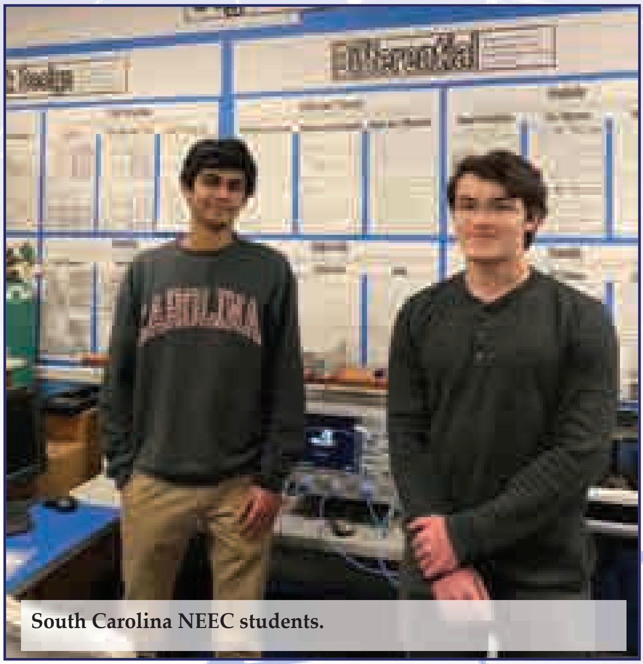
Jinqun Ge and Guoan Wang, "Thin Film Enabled Engineered Substrate for Tunable Microwave Applications," submitted to IEEE 2020 International Wireless Symposium, Shanghai, China, May 2020.

Jinqun Ge and Guoan Wang, "Characterization of Thin Film Enabled Engineered Substrate for RF Applications," submitted to IEEE 2020 Antenna and Propagation Symposium, Quebec, Canada, July 2020.

Jinqun Ge and Guoan Wang, "Thin Film Enabled Engineered Substrate for Miniaturized Antennas with Improved Bandwidth," submitted to IEEE 2020 Antenna and Propagation Symposium, Quebec, Canada, July 2020.



South Carolina NEEC students and their professor.



South Carolina NEEC students.

NSWC Dahlgren

Assisted Model-Based Systems Engineering (A-MBSE)

Professor: Alejandro Salado

Technical Capability Alignment:
DD01 Force and Surface Platform Level Warfare Systems Analysis and Modeling

Virginia Polytechnic Institute and State University

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

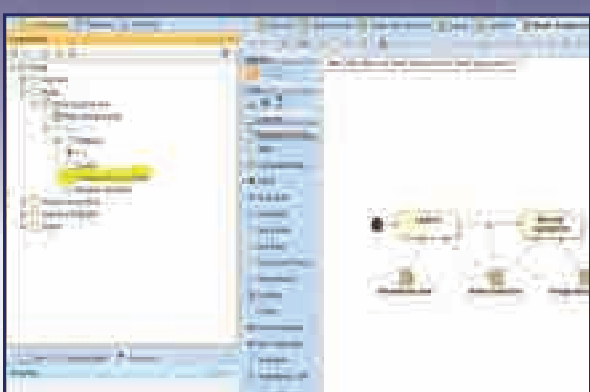
Development of an AI-based or expert-system-based virtual systems engineering assistant requires three principal tasks: identification of modeling gaps, behavioral modeling, and process design. This NEEC project surveyed formal modeling tools and identified requirements for extension of the industry standard system modeling language (SysML) to adequately model the problem space. During behavioral modeling, the team has constructed a set of rules and conceptual algorithms for evaluating behavioral models in SysML. The team also created an initial script to read and write SysML models in the Cameo System Modeler environment, and it prototyped some of the rules as scripts. During the process design, an undergraduate design project developed an understanding of engineering practices that could benefit from modeling in the Navy enterprise and collected information relevant to the time/effort of certain practices (in particular, project reviews and requirements).

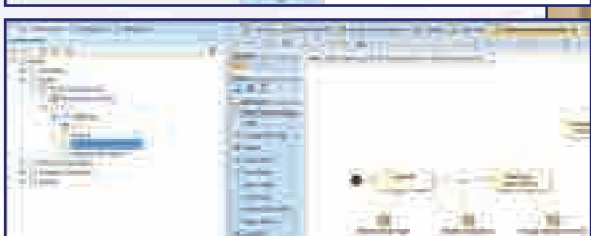
Two conference papers present results from this effort:

P. Wach, and A. Salado, "The Need for Semantic Extension of SysML to Model the Problem Space," Conference on Systems Engineering Research (CSER), Redondo Beach, CA, 2020. Submitted.

P. Wach and A. Salado, "Model-Based Security Requirements for Cyber-Physical Systems in SysML," Systems Security Symposium, Crystal City, VA, 2020. Accepted.

Four undergraduate and two graduate students are supporting this effort, which provides exposure to cutting-edge systems engineering tools and methodologies.





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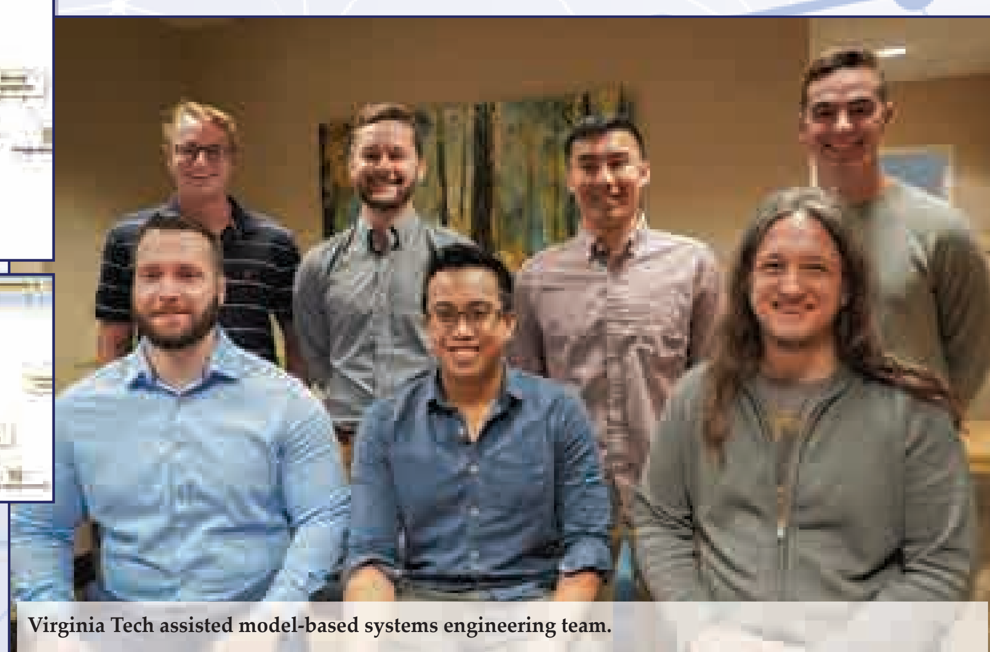


Virginia Tech assisted model-based systems engineering team.

Development of Self-Sealing and Self-Decontaminating Smart Apparel: Toward Breathable Personal Protection Gear

Professor: Konrad Rykaczewski

Technical Capability Alignment: DD20 Chemical, Biological, and Radiological Defense Systems

Arizona State University

Personal protective equipment for dealing with chemical and biological attack is notoriously difficult to wear. In particular, typical HAZMAT suits are typically impermeable plastic; as a warfighter performs the mission, the heat and humidity inside a typical HAZMAT suit can build to intolerable levels.

This research effort seeks to create a breathable material that seals itself on contact with organic liquids. Under the leadership of Professor Rykaczewski, students have developed a novel polymer that swells highly when exposed to a wide range of organic fluids. When it is used to coat a breathable mesh, the students have demonstrated that a material can seal itself safely when exposed to sensible drops (microliter volume regime).

Robust multiphysics modeling and simulation efforts, anchored by validation testing with polymers of known behavior such as polydimethylsiloxane, have led to the development of predictive tools for estimating polymer behavior. These models (picoliter volume regime) permit extension of polymer bead and material mesh designs to handle the aerosolized droplets that may be encountered in a chemical warfare attack.

This research has supported two full-time students through their Ph.D.s. It has also supported an undergraduate working in the lab to develop a swelling polymer, as well as a master's candidate thesis on verification of the polymer modeling. Through this project, three students were able to attend the annual NEEC Day presentations. One of these students is now an NREIP intern at NSWC Dahlgren Division.

Potential future expansion of this research includes the development of swelling polymers that incorporate catalysts designed to neutralize chemical warfare agents. Such a capability would represent a very large improvement in the current state of the art in HAZMAT equipment.

Dr. Akshay Phadnis and a student prepare for a polymer test.

Dr. Akshay Phadnis and a student test the swelling properties of polymer gels in a custom setup.

Enabling Deterministic Behavior in Virtualized Multi-Core Environments

Professor: Amro Awad

Technical Capability Alignment: DD40 Surface Combat Computing Systems S&T, RDT&E

University of Central Florida

The purpose of this project funded by the Naval Engineering Education Consortium (NEEC) is to develop techniques for isolating physical central processing units to specific logical domains within complex systems. Doing so ensures that critical functions are guaranteed adequate computational resources, thereby ensuring determinism and ultimately system safety and reliability.

The University of Central Florida (UCF) is investigating mechanisms to isolate physical CPUs allocated to different domains in mixed-criticality systems. UCF has devised and evaluated mechanisms that dynamically reallocate physical CPUs across domains based on their needs and thus minimize the underutilization of physical CPUs that could result from statically pooling resources. UCF has also explored new mechanisms and algorithms to leverage commercial vendors' support for quality of service and performance isolation in shared resources such as cache and memory.

UCF is exploring different ways to partition shared resources while considering security (resistance for side-channels across domains), performance and utilization. To better understand potential improvements for cache isolation and memory partitioning implementations in hardware, one student has been closely exploring how to implement deterministic multi-core processors by using open-source RISC-V processors. In summary, UCF is exploring how to boost determinism in virtualized systems through software-only approaches, hardware-assisted approaches that leverage support in commercial processors, and potential hardware changes viable through supporting determinism in open-source hardware processors.

The NEEC program at UCF has supported seven undergraduate students and two Ph.D. students. Some students who demonstrated solid technical capabilities and a passion for the project are planning to continue as Ph.D. students starting in the fall 2020 semester. Currently, the NEEC program supports three undergraduate students and one Ph.D. student, and it continues to invite new students to participate for one or more semesters.

Central Florida NEEC students working on their project.

NSWC Dahlgren

Dimensionality Reduction of Streaming Big Data for Clustering, Classification and Visualization via Incremental Multi-Linear Subspace Learning

Professor: Randy Hoover

Technical Capability Alignment: DD40 Surface Combat Computing Systems S&T, RDT&E

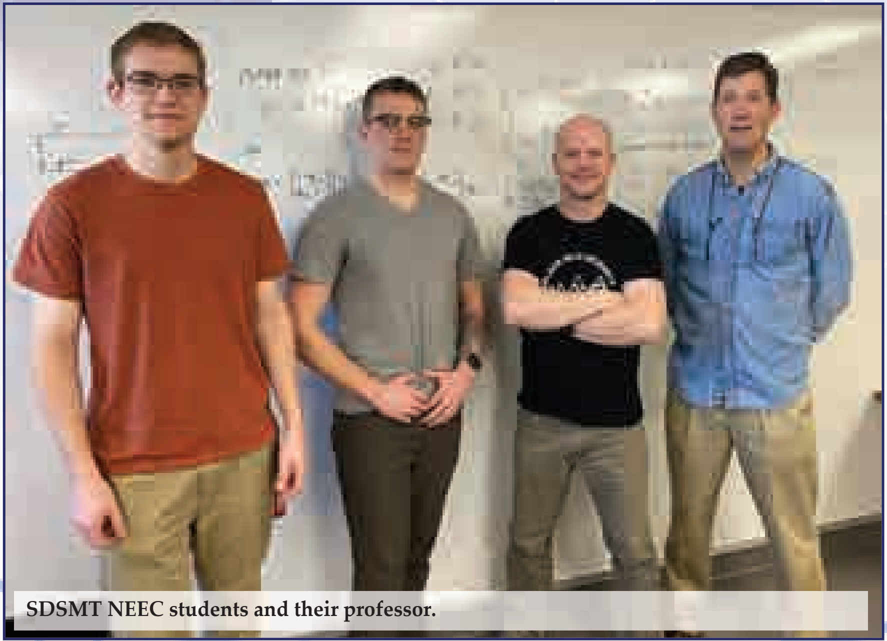
South Dakota School of Mines and Technology

Under a NEEC grant awarded in 2019, the South Dakota School of Mines and Technology (SDSMT) is working with the Applied Mathematics and Data Analytics group at the Naval Surface Warfare Center, Dahlgren Division, on a new methodology for analyzing large complex data sets.

Given a single set of data, the tools of linear algebra provide an efficient means of extracting key features for subsequent analysis. When multiple sets of data must be analyzed, the tools of multilinear algebra – specifically, tensor decomposition – are appropriate for key feature extraction. Using conventional techniques, an entire tensor decomposition is computed every time a data stream is updated with new information. With such an aproach, the computational complexity increases rapidly as data accumulates, and analysis quickly becomes infeasible.

Under this NEEC grant, SDSMT is developing a “streaming” algorithm that allows quick updating of a tensor decomposition – on the fly – as data are acquired instead of recomputing the tensor decomposition across the entire data set at every update. One application is the analysis of streaming video images. However, the techniques developed by SDSMT are quite general and extensible to numerous problem domains, such as analysis of network data for anomalous behavior, detection of network intrusion, tracking IP addresses, and visualization of complex networks.

SDSMT’s overall project goals are to reduce the dimensionality of large data streams and to cluster/classify large datasets by using Multi-Linear Subspace Learning (MSL). Initially, the team was working with large image datasets (video streams) with the goals of both dimensionality reduction and subspace updating. The overarching ideas are to use initial data collection to compute a reduced dimensional subspace that can be used for efficient clustering, classification, and data visualization. However, once new data arrives in the data stream, updating the subspace (as opposed to completely recomputing it) is essential for the real-time nature of streaming data. SDSMT research has extended some classical results from linear algebraic eigenspace; updating to their multilinear algebraic counterparts resulted in real-time subspace updating for clustering, classification, and visualization.



SDSMT NEEC students and their professor.

NSWC Dahlgren

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

Professor: David Wetz

Technical Capability Alignment:
DD12 Directed Energy Systems RDT&E

University of Texas at Arlington

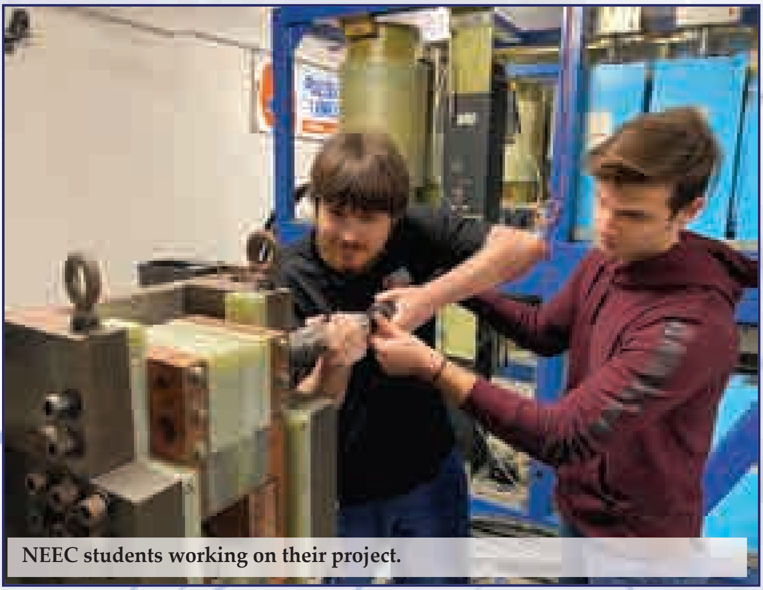
The purpose of this project funded by the Naval Engineering Education Consortium (NEEC) is to develop a rigorous understanding of dielectric breakdown phenomena. Such understanding is critical for the safe and economical design and employment of insulators critical to high energy pulsed power systems such as electromagnetic railguns.

Several new high voltage pulsed power systems are in various stages of the research and development (R&D) cycle. The operational voltage and energy across all these systems varies widely; therefore there is no one approach that can be used to dielectrically insulate them. Additionally, each system has its own operational performance and environmental requirements that must be considered.

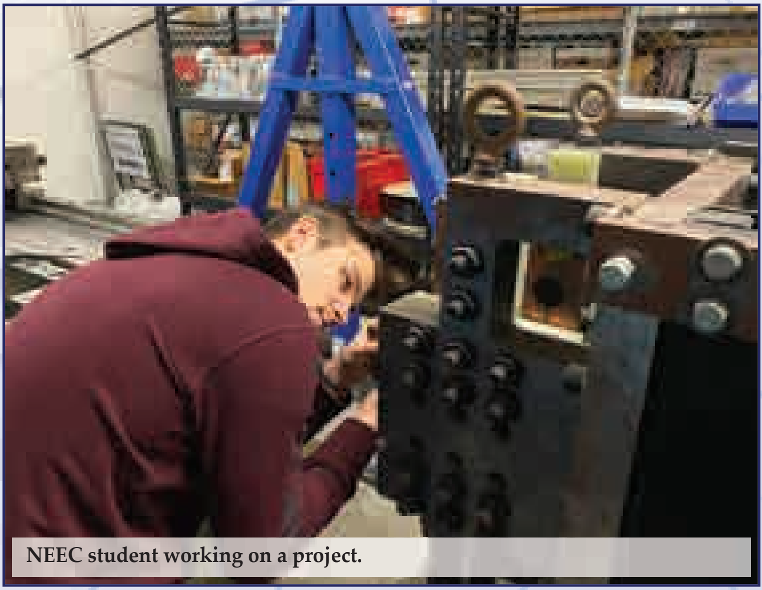
How insulator materials perform, age, degrade, and eventually fail is different in each use case and is not well understood in many cases. There are fundamental gaps in our understanding of breakdown phenomena. While many models for dielectric failure exist, most are derived from empirical data and are therefore not extensible to novel geometries or environments.

The electromagnetic railgun (EMRG) program is funding this NEEC project, which addresses some of the unique EMRG breakdown requirements. EMRG requirements differ from other pulsed power or high voltage transmission systems in multiple ways. The operational voltage in an EMRG system is low (<10 kV) but the stored energy is very high (100s of MJ). This relatively low voltage makes breakdown less probable, but the extremely high energy means that if breakdown does occur, it can easily become a catastrophic failure with potential safety implications. As an EMRG is intended to be a ship fielded system, the environmental demands are incredibly variable and challenging so they will certainly play a role in how all aspects of the system, including how the insulators perform, age and fail. The ultimate aim of this work is to lead the U.S. Navy EMRG community to a better understanding of insulator creepage and clearance requirements in unique operational and environmental conditions to prevent failures.

This NEEC effort is providing three undergraduate students with unique, hands-on experience with pulsed power systems.



NEEC students working on their project.



NEEC student working on a project.

NSWC Dahlgren

Characterization and Diagnostics of Electric Railgun Muzzle Arc Plasma

Professor: Angel Gonzalez

Technical Capability Alignment: DD11 Conventional and Electromagnetic Gun Weapon Systems RDT&E

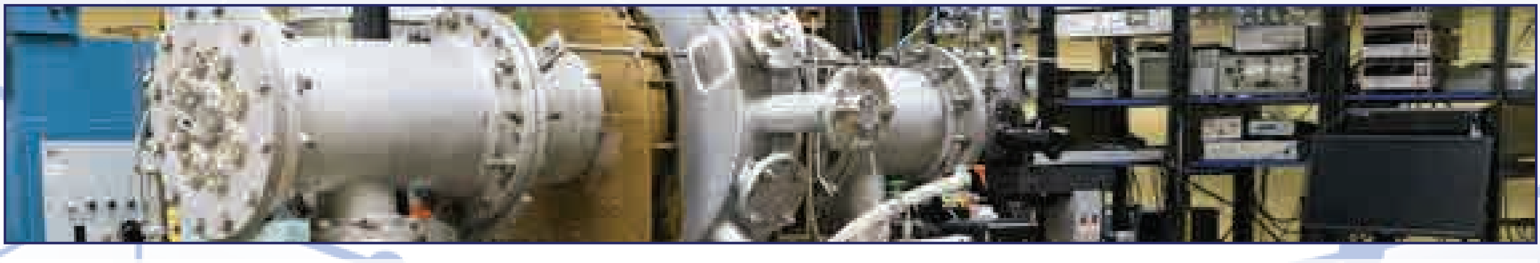
Polytechnic University of Puerto Rico

Under a NEEC grant awarded in 2019, the Polytechnic University of Puerto Rico is characterizing the plasma environment generated at the muzzle of a railgun during firing. The muzzle flow environment is complex, with a high-speed flow consisting of a diverse range of ionic components, extremely high temperatures, and possible secondary arc formation. Backflow of metal vapor from this region into the railgun can influence the in-bore environment and firing of subsequent rounds.

Under this research grant, the Polytechnic University of Puerto Rico (PUPR) has undertaken theoretical research into relevant arc plasma phenomena. PUPR has reviewed relevant literature about the characteristics of high pressure plasmas and researched methods for their characterization, to determine the relevant parameters. The Naval Surface Warfare Center, Dahlgren Division, is providing theoretical and experimental bounds on energy and time that PUPR will use to estimate plasma parameters (primarily electron temperature and density).

Current research under this NEEC grant involves determining specific parameters that must be measured during railgun tests to verify plasma parameters. Should current instrumentation or methodologies prove unsuitable, PUPR will recommend changes to railgun diagnostic instrumentation.

Professor Angel Gonzalez and students.



Plasma machine being used.

NSWC Indian Head

Dense Low Z Frameworks for Energy Storage

Professor: Dr. Choong-Shik Yoo

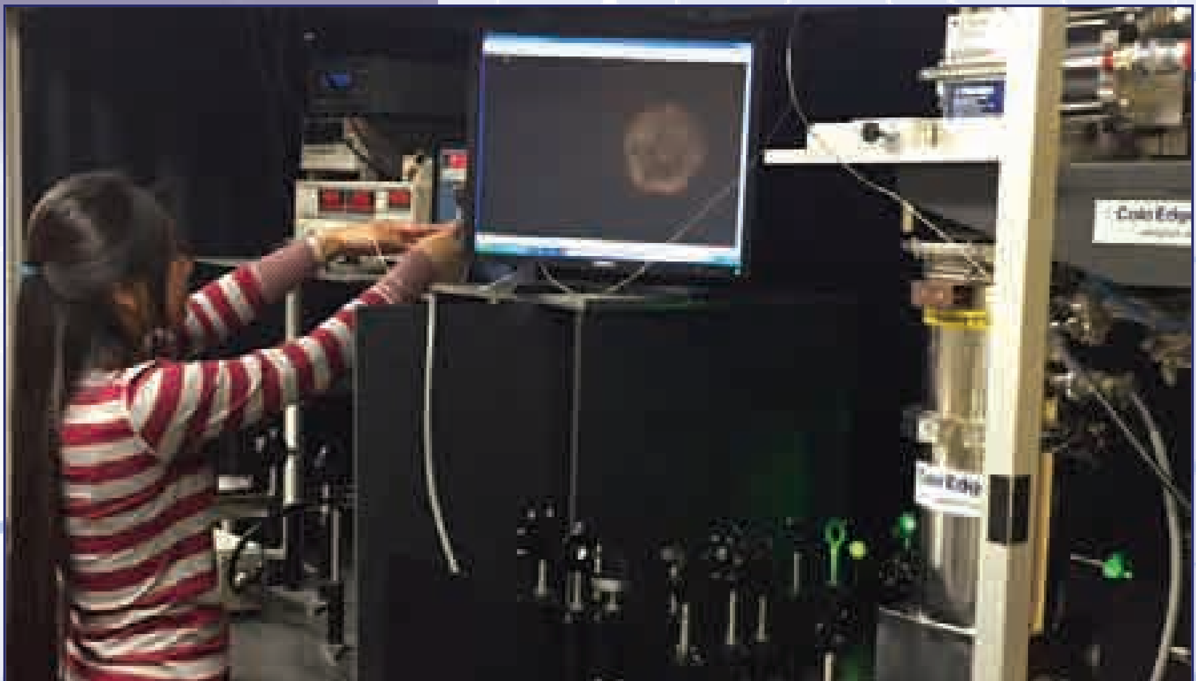
Technical Capability Alignment: IH10 Energetic and Ordnance Component and Ordnance Systems for S&T, Emergent and National Need Requirements

Washington State University

The goal of this project is to develop polymeric N_2 and/or nitrogen-rich polymer at relatively low pressures, which can be recovered at ambient conditions.

The project's approach is to use various forms of nitrogen-rich compounds as the precursors to synthesize similar forms of nitrogen polymers. Those include nitrogen-rich molecules, ionic nitrogen salts, metal nitrides, and simple azides. The rationale for these efforts follows the concept that these precursors are considerably higher in density (1.52 g/cm3) than N_2 molecules (~1 g/cm3) and therefore can be considered as intermediates toward high density (>3.5 g/cm3) nitrogen-rich polymers.

A wide range of novel nitrogen products have been reported based on the computational structural search and optimization, which include N_5 rings, N_5^+ chains, N_6 chains, N_6 rings, polymeric nitrogens, and N_8 molecules. Considering the similar nitrogen arrangement and stoichiometric considerations, the project has investigated hydrazinium azide (HA; $(N_2H_5)^+N_3^-$) at high pressures aimed at the synthesis of predicted stable molecular nitrogen allotropes (N_8 or N_6 in particular) or similar nitrogen dominant ionic products (such as N_5^+ ring or V-shaped N_5^+ ions) at high pressures.



WSU student evaluating high-pressure phases of nitrogen rich compounds.

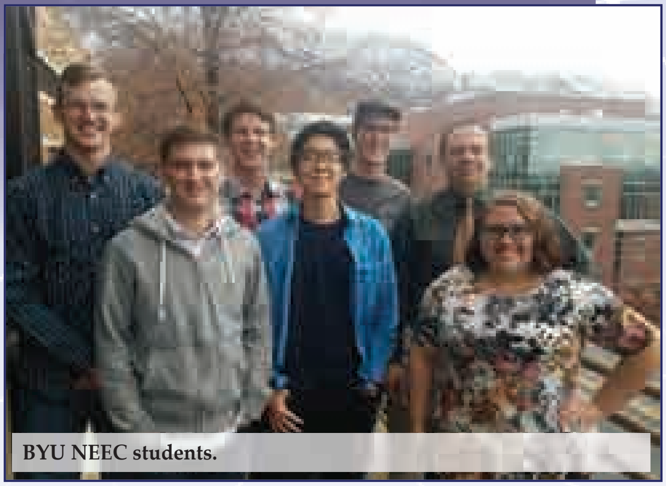
Determination of the Effects of Thermal and Mechanical Stress on PBX Binder Materials and the HE/Binder Interface

Professor: James E. Patterson

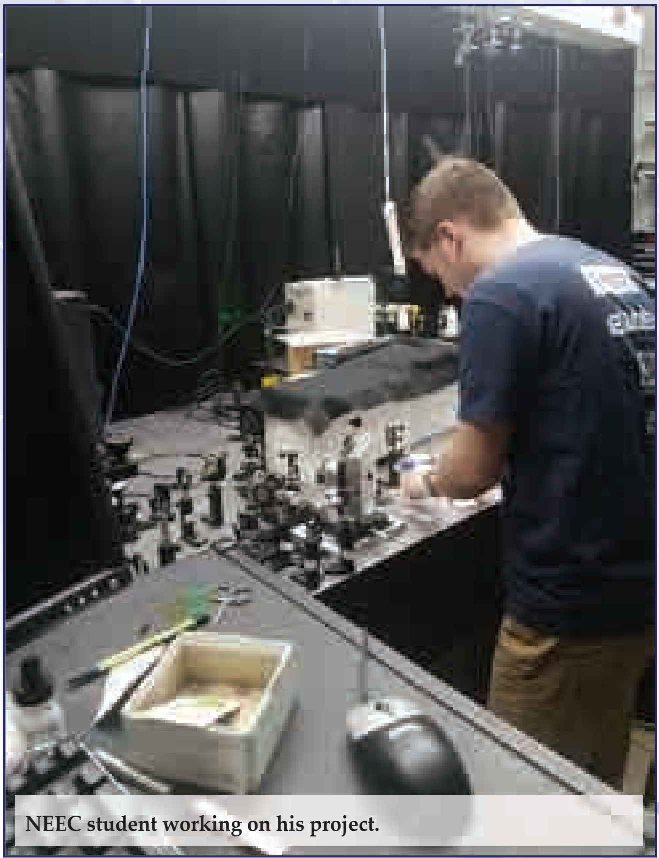
Technical Capability Alignment: IH10 Energetic and Ordnance Component and Ordnance Systems for S&T, Emergent and National Need Requirements

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. This project's 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.



BYU NEEC students.



NEEC student working on his project.

NSWC Indian Head

Reactive Material Formulations for Additive Manufacturing

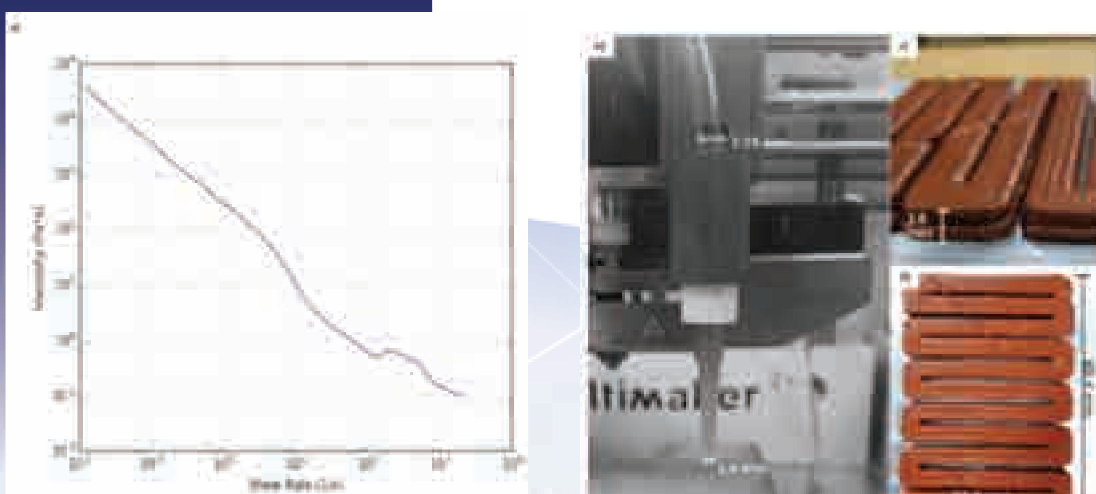
Professors: Kevin C. Galloway, Kelsey Hatzell, and Alvin Strauss

Technical Capability Alignment: IH10 Energetic and Ordnance Component and Ordnance Systems for S&T, Emergent and National Need Requirements

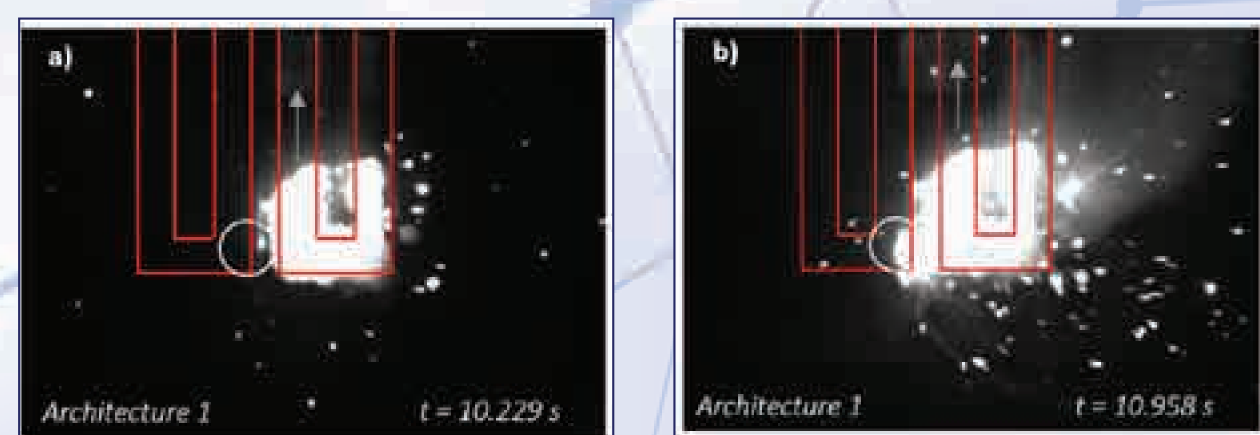
Vanderbilt University

The goal of this research is to develop reactive material (RM) formulations for additive manufacturing (AM) that enable rapid fabrication of customized reactive material architectures (RMAs) for constructive and destructive applications. The primary objective is to develop, characterize, and test reactive material formulations – the combinations of a reactive material and a binder that will hold shape and ignite – that are suitable for AM using extrusion-based printing and screen printing platforms. In addition, the project aims to evaluate the capacity of RMAs to generate controlled, heat-intensive reactions that could in turn be used to support assembly and repair operations (e.g., welding, brazing) across a variety of scales (mm to meter) and materials including metal, plastics, and ccomposites. The project also intends to evaluate the potential of RMAs to predictably and safely support counter threat measures.

Based on previous work on developing an RM paste for additive manufacturing, the team utilizes a three-stage material synthesis process that places an emphasis on experimentation and incorporating results and insights from each stage to advance (or abandon) formulations. Specifically, the aim is to develop new RM formulations (rigid and flexible) that can react faster than current plaster-based RM pastes (greater than 3 mm/s). These new RM formulations will then be evaluated for their ability to produce mechanically stable and reactive architectures. The results from these experiments will be important for understanding the geometries and quantity of RM that will support constructive (e.g., brazing) and destructive applications as well as novel additively manufactured structures, such as gradient materials.



At left: Shear rate and viscosity data for the uncured thermite paste; at right: nozzle and tubing configuration for the syringe printing setup; and far right (top, bottom): printed thermite structures.



Images captured with a high-speed camera of a lateral thermite ignition initiation on a serpentine RMA in a time span of 0,7 s.

NSWC Indian Head

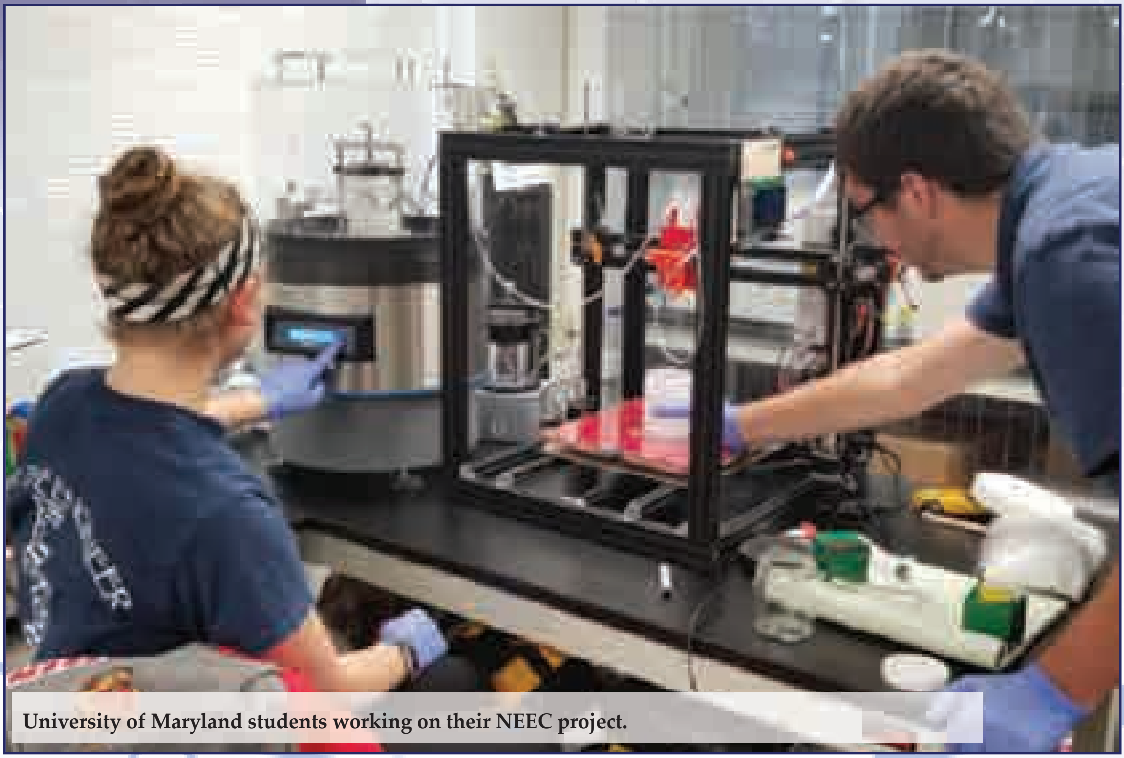
Mixing and Additively Manufacturing Energetic Material Systems

Professor: Dr. Ryan D. Sochol, Dr. Peter W. Chung

Technical Capability Alignment: IH10 Energetic and Ordnance Component and Ordnance Systems for S&T, Emergent and National Need Requirements

University of Maryland

The primary objective of this work, started in fall 2019, is to perform a systematic and quantitative characterization of the microstructures produced from the acoustic mixing processes of surrogate energetic materials. Resonant acoustic mixing (RAM) technology operates by applying low-frequency, high-intensity acoustic energy (up to 100 g) to mix throughout an entire mixing vessel immediately and continuously for numerous types of materials, including energetic, binder, plasticizer, and curing agents. A key advantage of RAM is that it is a non-contact mixing technology—i.e., neither the impeller blades nor any other engineered devices are used inside the mixing vessel. The time and labor associated with mixing can also be improved versus conventional mixing methods, with the mixing times often reduced by orders of magnitude because of the ability to replace mixing vessels in seconds (without the need to clean mechanical components of conventional mixers, such as impeller blades). The engineering simplicity of the mechanical process also affords new opportunities for mix-in-case processing and scaling to volume production.



University of Maryland students working on their NEEC project.

NSWC Indian Head

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

Professor: Dr. Grant Crawford

Technical Capability Alignment: IH10 Energetic and Ordnance Component and Ordnance Systems for S&T, Emergent and National Need Requirements

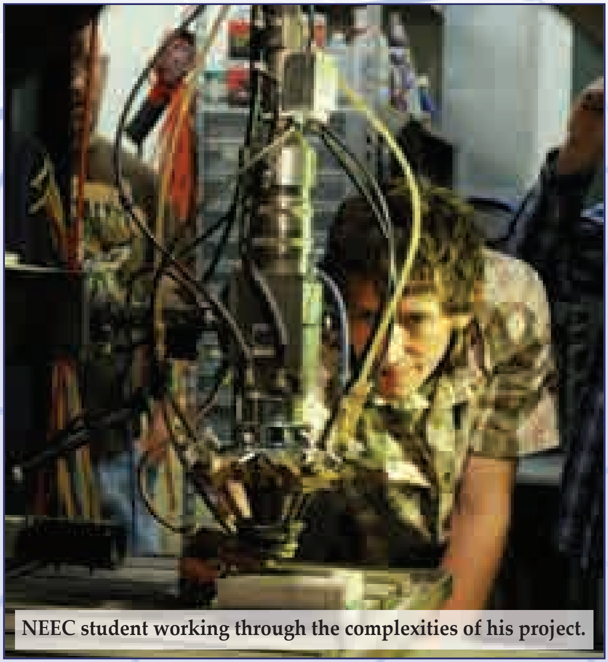
South Dakota School of Mines and Technology

Additive manufacturing (AM) has the potential to revolutionize munitions manufacturing, with such advantages as rapid transition from prototype to volume production, faster material release, and the 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 are required. One of the challenges is the AM fabrication of large metallic structures for munitions applications.

The South Dakota School of Mines and Technology (SDSMT) 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 performed an initial metallurgical characterization of artillery steels, developed a custom, high performance artillery steel AM powder (in collaboration with a third party), and designed and initiated AM system modifications to permit manufacturing of large caliber munitions.

SDSMT student enthusiastically working on his NEEC project.


NEEC student working through the complexities of his project.

NUWC Keyport

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

Professor: Yun Shin

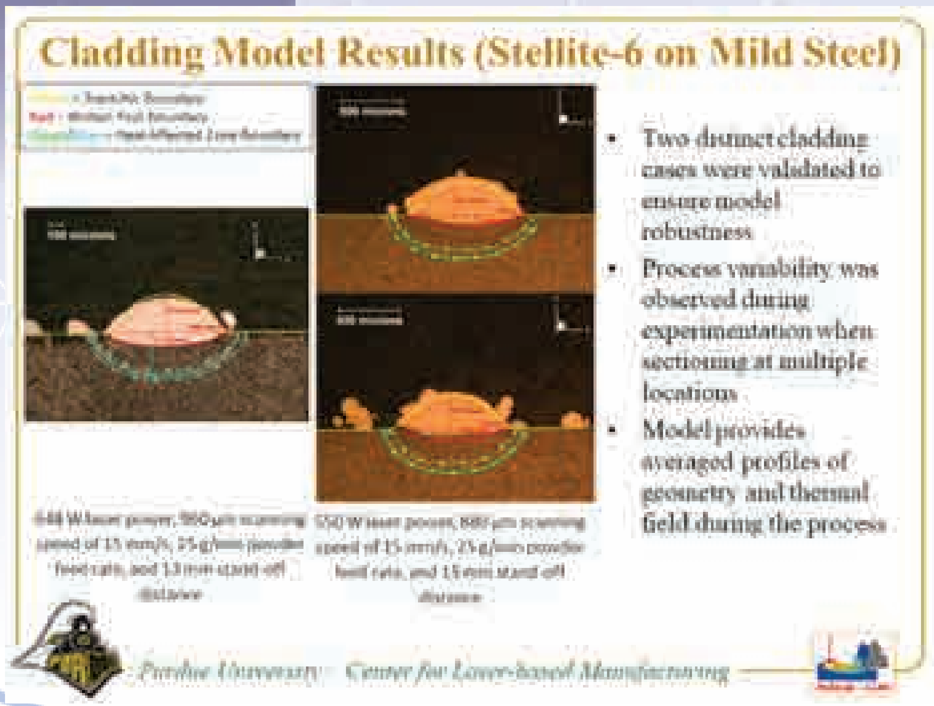
Technical Capability Alignment:
KP04 Torpedo and Unmanned Undersea Vehicle Maintenance and Repair

Purdue University

The goal of this project is to develop cost effective technologies for rapidly building and repairing various molds and toolings used in the foundry industry, such as sand molds, and also for achieving bimetallic cladding on various metallic alloys. To achieve this goal, the project will aim at (1) establishing the capabilities for rapid 3D printing of cores with conformal cooling lines; (2) developing a seamless strategy for rapid repair of various toolings and demonstration; (3) determining the range of possible materials for bimetallic cladding and developing a design of experiment; (4) cladding a representative sample of the most promising bimetallic cladding materials and optimizing the microstructure for wear resistance; and (5) characterizing the resultant microstructure, wear resistance, and mechanical properties. Both the powder bed and directed energy deposition techniques will be used, and automatic reconstruction of part drawings from actual legacy or damaged parts and an automatic laser scanning path procedure will be developed.

This research is of high interest to the Navy due to the potential return on investment for performing these types of repairs. Ships and submarines have many large and complex pieces of machinery that have to endure a corrosive saltwater environment. Replacement of this equipment is very expensive in both removal and installation labor and in the replacement cost of the machinery components. For this reason, the Navy needs the ability to perform dimensional restoration of this equipment (versus replacement) and would like the repairs to have greater repair longevity through the use of better alloys for corrosion and wear.

The NEEC project with Purdue University is an opportunity for both organizations to explore new deposition techniques, process/recipe knowledge, and metallurgical findings. The optimal result of the Purdue University research would be to leverage the findings from this work to improve Keyport's capabilities to perform dimensional repair.



NUWC Keyport

Development of Autonomous Control for Multiple Vehicle Platforms

Professor: Dr. May-Win Thein

Technical Capability Alignment:
KP02 Independent USW Systems Test and Evaluation and Experimentation

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 test bed is needed to test these autonomous systems with high-integrity field testing, especially when autonomous vehicles systems are composed of different platforms (i.e., surface, underwater, and aerial). The purpose of this research is to continue to develop technology to enable autonomous control of a multiple platform collaborative vessel network to show proof of concept of multiplatform and cross-platform autonomous systems working collaboratively towards a common mission/goal. The mission for this research on a network of multiple unmanned underwater vehicles (UUVs) and autonomous surface vehicles (ASVs) is chosen, without loss of generality, as a seafloor mapping mission.

Because many of today's vessels are unstructured and often negotiate passing and crossing without following standard Collision Regulations (COLREGS), there has been an increasing amount of research dedicated to reliable autonomy methodologies, including those for multi-objective optimization and velocity obstacles. Therefore, an integrated aspect of this research is also to develop autonomous path planning technology.

All research is performed via the active participation of three generations of approximately 17 undergraduate and graduate students annually (altogether about 54 students). In all, 97 students (8 graduate students, 86 undergraduate students, and 3 high school students) have been involved in current and past NEEC research grants, of whom 22 undergraduates were supported as summer research interns. In addition, four students joined NUWC Keyport as full-time employees after graduation or NREIP Scholars, and dozens of other students took full-time employment at other U.S. Naval bases and/or naval/marine-based industries. Students participated in research spanning the areas of computer science, electrical engineering, computer engineering, systems engineering, mechanical engineering, ocean engineering, and IT.

UNH ASV Platforms.

Students testing ASV and ROV at UNH indoor underwater facilities.

NUWC Keyport

Obsolescence Management: Prediction and Visualization of Lifecycle Stage

Professor: Christina Mastrangelo

Technical Capability Alignment:
KP05 Obsolescence Management

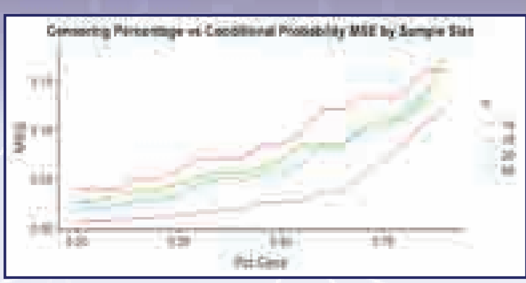
University of Washington

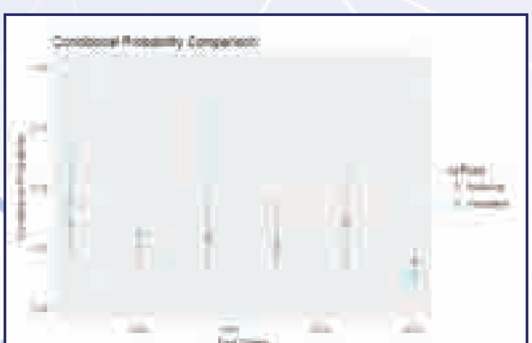
Diminishing manufacturing sources and materials shortages (DMSMS) describes a form of obsolescence in which a given part is no longer manufactured or available due to a lack of vendors and/or materials – or may become so soon. This causes problems for organizations that manage long-lived systems, such as fleet systems, telecommunications infrastructure, and weapon systems. Historical approaches to managing the risk associated with DMSMS have commonly been reactive, either when the needed item is no longer available or when the Navy has learned about an impending lack of availability.

This project's aim is to develop predictive methodologies using parametric modeling and simulation to generate likelihoods of a part or system becoming obsolete before manufacturers report obsolescence. This research effort is using two mechanisms: historical data analysis and simulation. To help test and develop the predictive methodology, a simulation-based environment is being used to generate parts data and evaluate the methodology. The motivation for this approach is that historical data is nontrivial to acquire, is not available for all part types, and may be sparse and incomplete. Simulation is used to evaluate and refine the proposed methodologies because ultimately the result is a set of robust algorithms for implementation in the Obsolescence Management Information System (OMIS). The simulation model development and validation was primarily completed in Year 1 of the project.

The validation of the model for COTS parts was completed in year 1. The next focus was on testing the prediction's robustness under different data quality scenarios via simulation, as well as working toward operationalizing the method with respect to robustness, data quality, and optimal parameters.

In year 3, UW is finalizing models from the research tto use in a new predictive tool being produced now for NUWC Keyport. These models will be incorporated with Keyport's machine learning models to give two methods to predict obsolescence for electronic parts. The tool should be completed in the third quarter of FY 2020, and the models should be delivered before April 2020. NUWC Keyport and UW are considering potential patent filings for the joint researches.






University of Washington (UW) NEEC team.

NUWC Newport

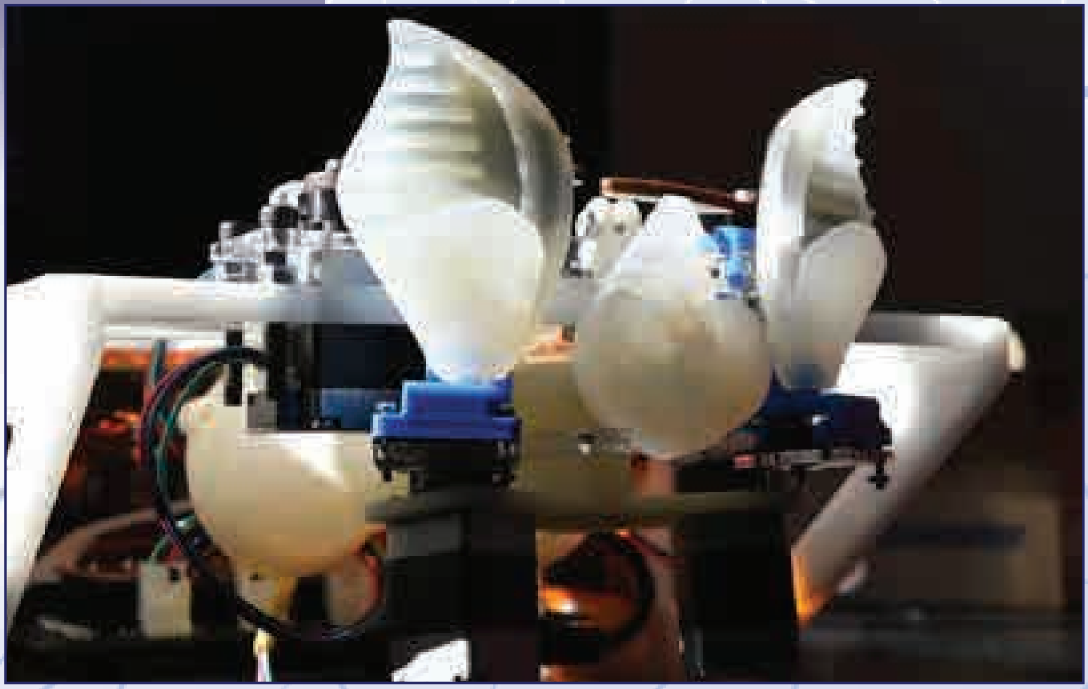
Bioinspired Broadband Sonar

Professor: Dr. Rolf Mueller

Technical Capability Alignment:
NP05 USW Sensor and Sonar Systems

Virginia Polytechnic Institute and State University

Bat species with particularly sophisticated biosonars have a unique dynamic periphery in which sound-diffracting baffles (i.e., noseleaves and ears) change shape during the emission of the ultrasonic sonar pulses/reception of the echoes. At the same time, bats with this dynamic are able to navigate in highly dense, highly complex natural environments - a capability that is not found in other bat species or man-made sonars. The goal of the project is to gain insight into the unique dynamic properties of these sophisticated bat biosonar systems and how their functional principles may be used for naval applications, such as guidance for autonomous underwater vehicles. To better understand the functional properties of a dynamic periphery, a biomimetic in-air sonar head is being developed. The sonar head mimics the non-rigid deformation of the noseleaves and ears. It is being tested in a laboratory context as well as in outdoor environments by using a drone and a zip-line platform. The biomimetic system is used to assess the dynamic encoding of sensory information in the system's periphery, especially with regard to target localization (direction finding) and target identification. Research conducted so far has demonstrated that non-rigid motions of biomimetic noseleaf and pinna shapes result in very substantial improvements to target direction finding, and the latest pilot data indicates the dynamic encoding of information on target class. If these dynamic principles for sensory information encoding can be implemented in technical sonars, they could lead to much more compact and computationally parsimonious sensors that would yet be more capable of delivering the information that is needed for navigation and guidance in complex environments.



Biomimetic sonar head with deformable noseleaf and ear shapes inspired by horseshoe bats. The system mimics the several degrees of freedom seen in the biosonar of the bats and is being tested in natural/outdoor environments.

NUWC Newport

Wave-Based Analysis of Distributed Acoustic Sensor Networks

Professor: Dr. Greg McDaniel

Technical Capability Alignment: NP20 USW Distributed Netted Systems

Boston University

Boston University is creating swarms of small autonomous boats that sense underwater sound and develop a collective intelligence and memory about their acoustic environment. The boats communicate their positions and measured sound to each other over a wireless mesh network. Each boat carries a hydrophone suspended below the boat as well as onboard electronics that include batteries, computer, digital acquisition system, GPS, autopilot, and wireless radio. The boat and its electronics are constructed almost entirely from commercial off-the-shelf parts, resulting in the least expensive oceanic mobile acoustic sensing platform known to us. Each boat is jet propelled and turns by differential thrusting. Students are creating and testing algorithms that determine the optimal motion of each boat in real time. The final product of this research will be a fully autonomous system that localizes, classifies, and tracks sources of underwater sound in the presence of noise.

Boston University undergraduate students preparing to test three acoustic sensing boats.

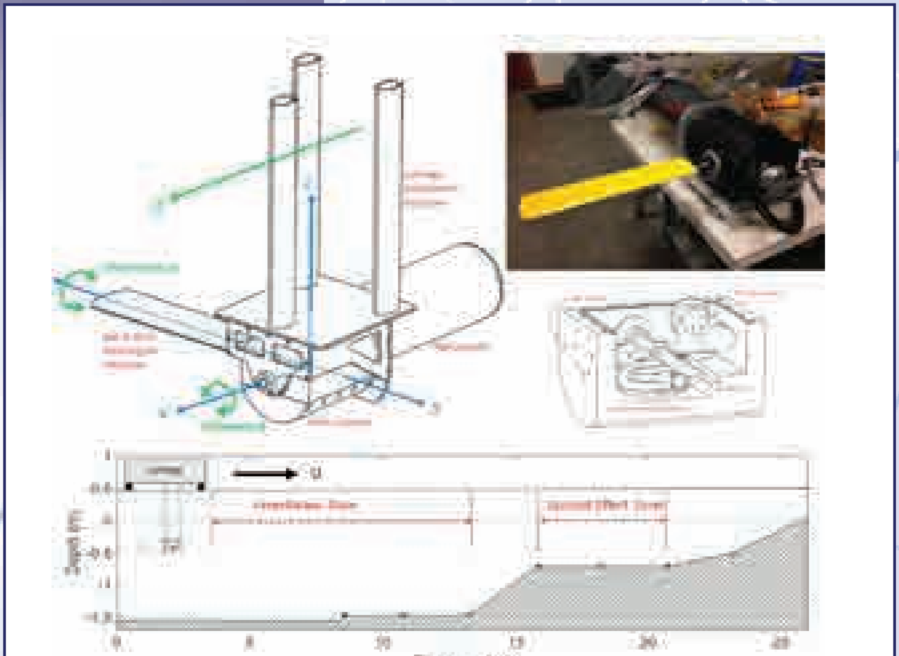
Modeling and Analysis of Bragg Scattering in Periodic Structures

Professor: Dr. Stephen Licht

Technical Capability Alignment: NP11 USW Autonomous Vehicles

University of Rhode Island

Conventional propeller-driven autonomous underwater vehicles (AUVs) cannot operate in dynamic environments, near obstacles, or close to the bottom. They have high roll stability and low actuator authority, and they use a decoupled linearized control approach that produces slow-moving vehicles with poor agility. In an effort to improve AUV agility, the U.S. Navy has funded the development of a number of oscillating foil-driven AUVs. Oscillating foils are a class of biologically inspired thruster that can vector propulsion forces more rapidly – and with higher authority – than conventional propellers. Foil-driven AUVs have the propulsion authority to perform aggressive maneuvers, such as banked turns, rolls, and flips. The purpose of the proposed effort is to develop and validate control algorithms and hydrodynamic models for foil-driven AUVs that take full advantage of their novel propulsion capabilities to enable them to perform aggressive, large-angle maneuvers and to operate efficiently and safely at boundaries. Target naval applications for agile vehicles include payload delivery, intelligence/surveillance/reconnaissance (ISR) and mine countermeasures (MCM) in shallow waters and rivers. Razor, currently at NUWC, a four-finned 200-kg AUV developed for hostile swimmer interdiction, will be used as the nominal target for simulation and experiment. Experiments with full-scale foils at NUWC Newport and at the Narragansett Bay Campus of the University of Rhode Island will be used to develop and validate foil propulsion models, which will then be incorporated into 6-degree-of-freedom simulation of the vehicle itself. In year 2, the primary effort will be centered around foil response when in close proximity to a hard bottom. In year 3, the effort will be centered around foil response to the free surface.



Details of experimental apparatus for near-bottom trials of oscillating foil propulsor. Top left: model of foil apparatus as mounted to moving carriage. Top right: foil mounted to apparatus. Middle-right: internal detail of force measurement location. Bottom: tank bathymetry allowing for free-stream and near-bottom operation of foil.

NUWC Newport

Shock Response of Composite Materials Subjected to Aggressive Marine Environments: An Experimental and Computational Investigation

Professor: Dr. Arun Shukla

Technical Capability Alignment: NP13 Torpedoes and Undersea Weapons

University of Rhode Island

Within the Navy there is an interest in constructing new lighter vehicles and structures from composite materials. These structures are subjected to aggressive marine environments during their service life, including high-salinity water and/or salt spray and ultraviolet radiation that can significantly degrade their performance over time. These effects are of particular concern when composite vehicles are deployed in a military setting where they may be further subjected to shock and/or blast loading. Therefore, there is a need to investigate how composite materials that have been exposed to marine environments respond to shock events and how these responses differ from an equivalently loaded virgin structure. This work will expand the current knowledge on the performance of marine composites throughout their useful service life when subjected to shock loadings. The emphasis will be on understanding the fundamental mechanisms of damage evolution and their relationship with the dynamic loading and aggressive marine environments. The goal will be to quantify the effect of prolonged exposure to aggressive conditions on the shock response of a composite structure. This will be accomplished using underwater explosive (UNDEX) loading experiments and accelerated life weathering techniques in collaboration with air-driven shock tube experimental methods developed by researchers at the University of Rhode Island. Computational simulations incorporating the physics from the experiments will be performed utilizing finite-element software. The successful completion of this project will result in an experimental methodology for testing the effects of prolonged seawater exposure on composite panels subjected to shock loading, as well as a modeling methodology for the prediction of the response of aged composite materials subjected to shock loading. In addition, the quasi-static as well as high-strain-rate properties of environmentally aged composite panels before and after shock loading will be evaluated to improve the overall understanding of the behavior of these materials in the field.

Graduate student, and now a full-time employee at NUWC Newport, preparing the high-speed cameras for experiments on the implosion process of hydrothermally degraded composite tubes.

NUWC Newport

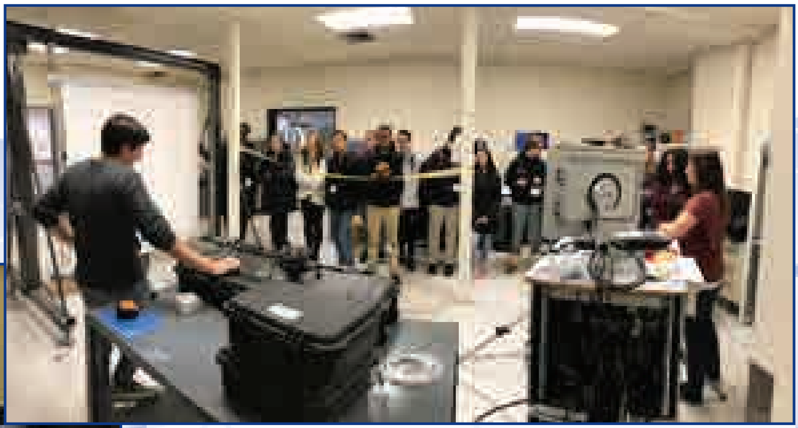
Modeling and Analysis of Bragg Scattering in Periodic Structures

Professor: Dr. Chris Niezrecki

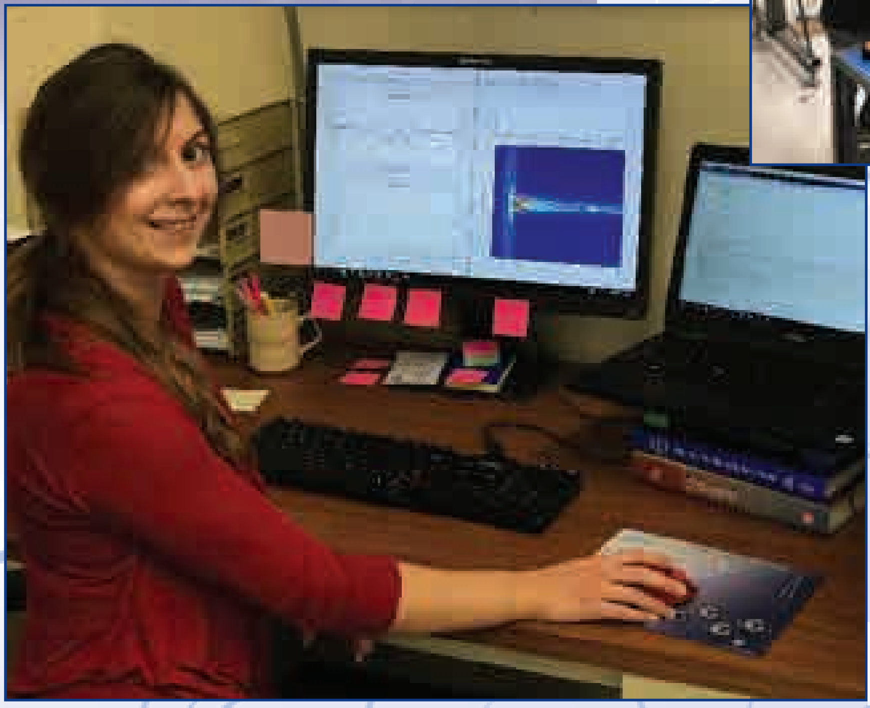
Technical Capability Alignment: NP13 Torpedoes and Undersea Weapons

University of Massachusetts Lowell

Research at UMass Lowell is investigating a way to improve hull-mounted transducer arrays that can achieve better source localization and/or detection. If equally spaced ribs are embedded in the arrays, the array signal excited by an acoustic source is reflected from the ribs, scatters, and combines to create a shorter-wavelength replicate signal. It has been proposed that the replicate signal can be used to estimate the bearing of the original noise source. The research is focused on characterizing the benefits that these replicate signals can provide for underwater localization. Closed-form MATLAB models, Comsol FEA models, and experimental tests are used to study the replicate signals. To help validate the models and simulations, a NUWC ribbed test panel is being experimentally tested within the Structural Dynamic and Acoustic Systems Laboratory at UMass Lowell. The potential benefits of this project include improved localization precision, better source signal-to-noise ratio, and reduced array size.



Ph.D. graduate student (right) presenting the NUWC research project while conducting a laser scan of the panel (left) to a tour group of students from Weston High School on December 8, 2017.



Ph.D. graduate student researcher processing experimental data from the NUWC ribbed test panel at UMass Lowell.

NUWC Newport

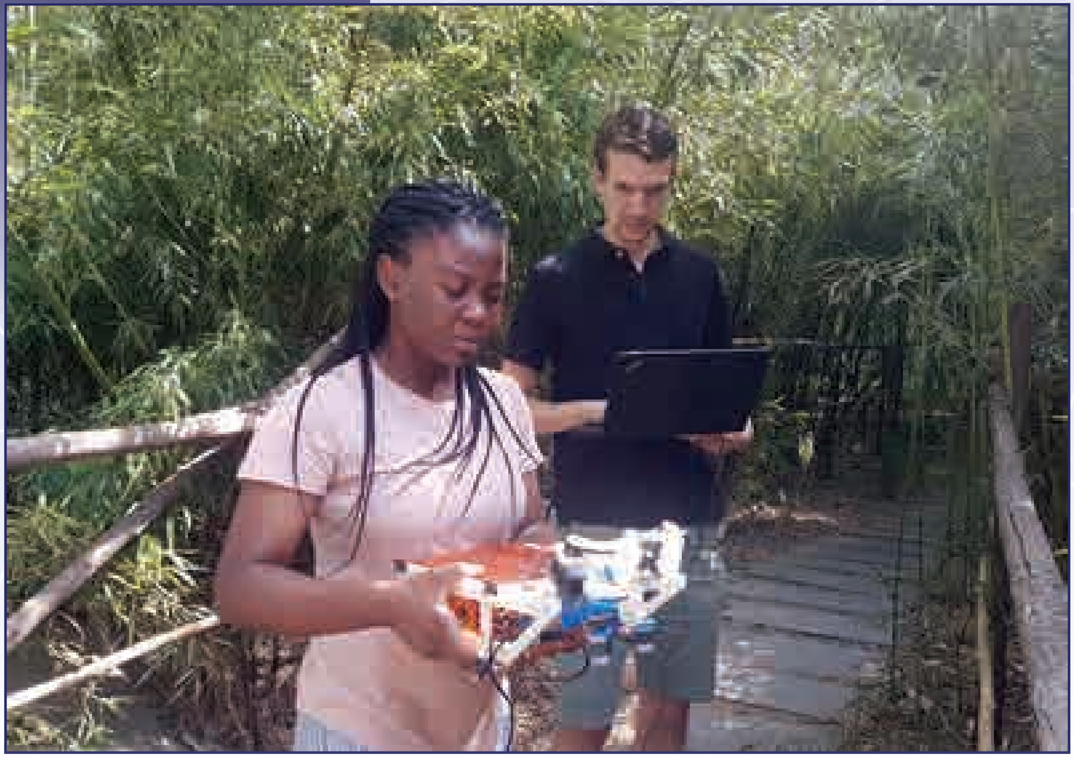
Bioinspired Physical Deep Learning Paradigm for Sonar Sensing in Cluttered Environments

Professor: Dr. Rolf Mueller

Technical Capability Alignment:
NP05 USW Sensor and Sonar Systems

Virginia Polytechnic Institute and State University

The ability of bats to navigate through dense vegetation based only on streams of ultrasonic biosonar signals remains unmatched by any man-made sonar. Understanding and reproducing the biosonar capabilities of bats could thus have a transformative impact on achieving autonomy for sonar platforms in complex environments such as shallow water. A key property of the most sophisticated biosonar systems found in bats is a dynamic periphery where the animals change the shapes of elaborate baffle structures that are used for ultrasound emission and reception through muscular actuation. The goal of the project is to use machine learning and neuromorphic computing methods to understand how such dynamic properties can be controlled to become part of adaptive and dynamic sonar systems.



A Ph.D. student in Computer Science at Virginia Tech and an undergraduate student in Biology, who is a summer student from Winston-Salem State University – an HBCU, are testing the bioinspired sonarhead in a natural outdoor environment.

NUWC Newport

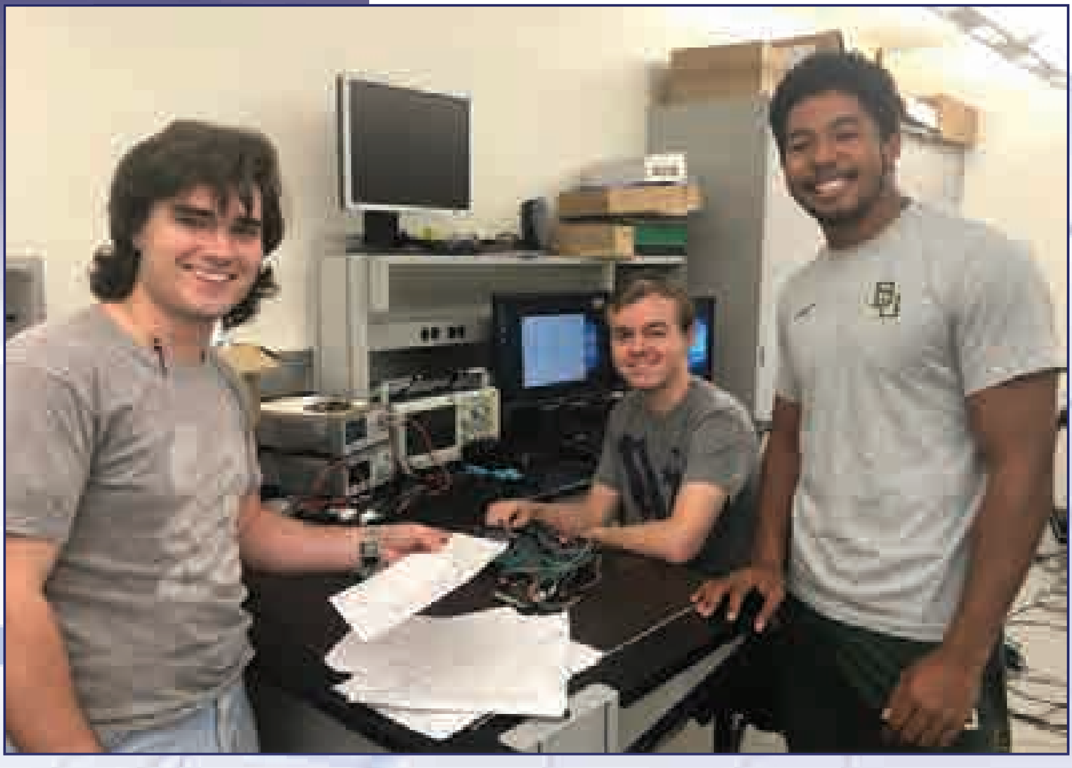
Improved Robot Autonomy Using Neuromorphic-Based Stochastic Computing

Professor: Dr. Scott Koziol

Technical Capability Alignment:
NP11 USW Autonomous Vehicles

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



"Three Baylor University NEEC students pose in their research lab next to NEEC hardware (the green neuron circuit board in the foreground on the lab bench). These students are all working towards Masters degrees in Electrical and Computer Engineering. They are working with their Baylor faculty advisor Dr. Scott Koziol, and with NUWC mentors Dr. John DiCecco and Dr. Eugene Chabot on improved robot autonomy using neuromorphic-based stochastic computing.

NUWC Newport

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

Professor: Dr. Gila Stein and Dr. Michael Kilbey

Technical Capability Alignment: NP15 USW Environmental Assessment Effects Analysis

University of Tennessee, Knoxville

The goal of this research program is to develop durable coatings that protect large-area surfaces from marine fouling. The approach is based on multi-functional surface-active macromolecular brushes that spontaneously accumulate and self-organize at the surface of an elastomeric coating. The team will develop structure-property relations that explain how chemical, mechanical and topographic heterogeneities in these systems will affect antifouling character. Graduate and undergraduate students will be trained in materials synthesis, coating deposition, a variety of surface analysis techniques, and biofouling/marine fouling assays.

Two Ph.D. candidates at UTC – one in Chemistry and one in Chemical and Biomolecular Engineering – are running a column, a step in the synthesis of surface-active molecular brushes.

NUWC Newport

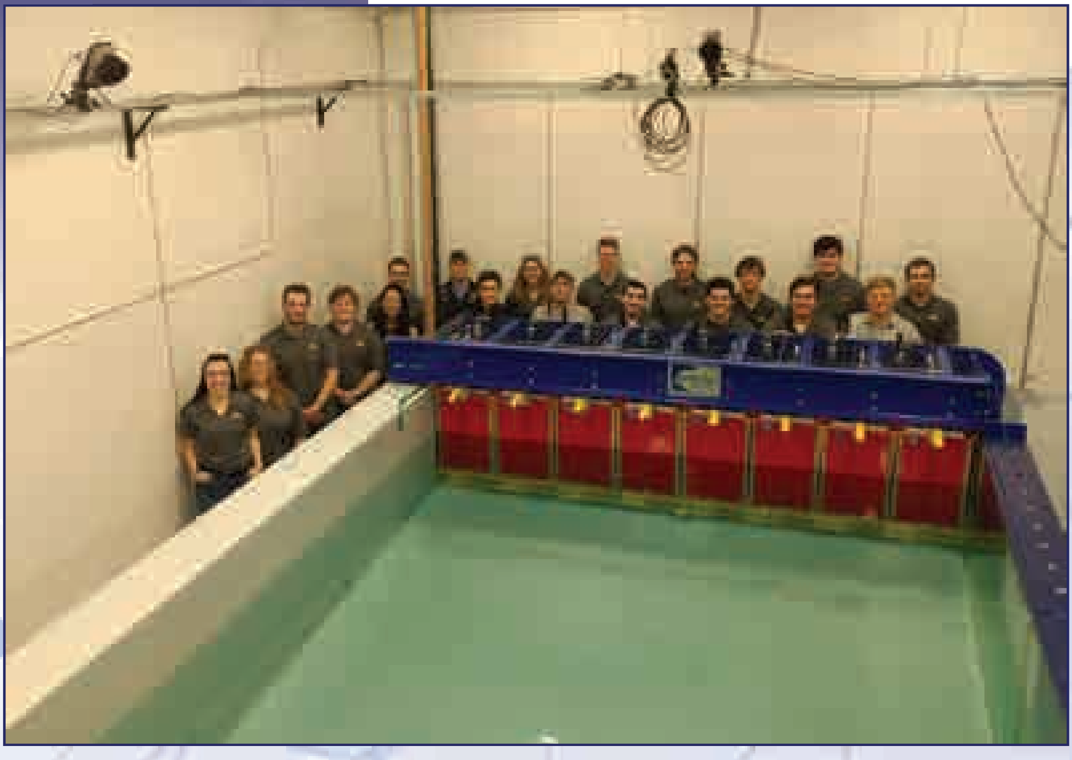
Localization, Tracking, and Classification of On-Ice and Underwater Noise Sources Using Machine Learning,

Professor: Dr. Timothy C. Havens and Dr. Andrew Barnard

Technical Capability Alignment: NP05 USW Sensor and Sonar Systems

Michigan Technological University

Changing Arctic ice conditions warrant new study of acoustic localization, tracking, and classification of anthropogenic sources, important for situational awareness in the ocean battlespace. The main objective of this work is to provide hands-on, militarily-relevant education opportunities for students in under-ice acoustics and machine learning. The second objective of this work is to advance the understanding of multi-modal acoustic localization, tracking, and classification in ice-covered, shallow-water zones by using deep learning with acoustic vector sensor data.



Michigan Tech Strategic Education through Naval Systems Experiences (SENSE) Enterprise students in the MTU Wave Tank facility. Four NEEC students (in Mechanical Engineering, Electrical Engineering, and Software Engineering) are part of the SENSE Enterprise.

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: Dr. Arun Shukla

Technical Capability Alignment: NP13 Torpedoes and Undersea Weapons

University of Rhode Island

The U.S. Navy uses elastomeric coatings on structures for various reasons, including blast/shock survivability, reduction of moisture permeability, and additional resistance to chemical, physical, and biofouling deterioration. The project investigates the performance of these advanced elastomeric coatings and the integrity of the naval structures, after prolonged exposure to aggressive marine environments. The conditions considered will include exposure to saline water (simulating the ocean environment), ultraviolet (UV) radiation, high strain rates, and temperatures ranging from -40 °C to 70 °C. The degradation due to prolonged exposure is simulated by employing indoor accelerated aging methods, which use high temperatures.

A 2.1-m-diameter semi-spherical pressure vessel, with a maximum pressure rating of 1000 psi. Vessel is used to simulate the open ocean environment at different depths. Implosion and UNDEX behavior of weathered elastomeric coated cylinders are investigated using this facility.

NSWC Panama City

Design and Implementation of Communications-Constrained Path Planning Algorithm for Unmanned Vehicles Operating in Littoral Environments

Professor: Demetri Mavris in the Aerospace Department

Technical Capability Alignment: Unmanned Systems Engineering & Integration, Autonomous Operations, Joint Interoperability and Common Control

Georgia Tech Research Corporation

With the rise of unmanned vehicle technologies and the strong desire to use these technologies in naval missions, it is critical to resolve key challenges to using these vehicles operationally. One such challenge is the need for regular and reliable communications with the unmanned vehicle, which can be particularly difficult in a maritime operating environment. The maritime communications environment is characterized by a myriad of challenging signal attenuation effects and skip zones in communication signals. Various phenomena can affect the quality of transmission channels during intermittent communication between multiple unmanned assets, which can compromise mission success. Therefore, the Navy would greatly benefit from the ability to better predict and plan for these effects, which will depend on the specifics of the given mission scenario. The goal of the proposed effort is to help mitigate this operational challenge by developing path-planning algorithms that use information about the weather, geography, and communications technology aboard unmanned vehicles to perform path planning that increases confidence in having successful communications channels while still meeting key mission objectives. Furthermore, the project is designed to include key educational objectives, thus preparing the next generation of engineers to be ready and able to work in Navy-related careers upon graduation.

NEEC student as test rider.

The GT NEEC Team.

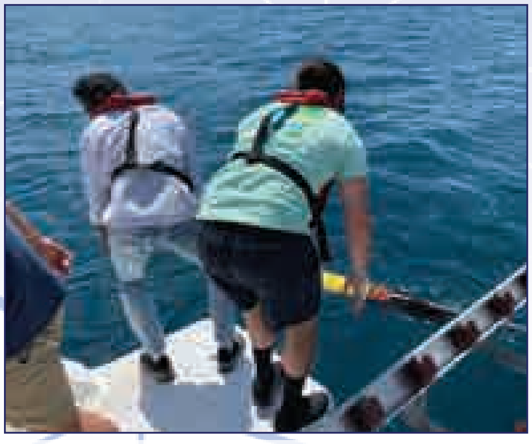
NSWC Panama City

Adaptive Sensing in Challenging Underwater Environments Using Multiple Autonomous Vehicles

Professor: Manhar Dahnak, Pak-Cheung An, Pierre-Philippe Beaujean

Technical Capability Alignment: MCM Detect and Engage Systems, Modular Mission Packaging, and Platform Integration and Handling

Students deploying the REMUS 100 AUV (2017).



Students and FAU engineers recovering the REMUS 100 AUV (2019).

Florida Atlantic University

The overall goal of the proposed effort was to support the development of affordable unmanned maritime systems in the form of marine networks of mobile, adaptive, and cooperating sensor platforms, for improved volumetric in-situ sensing in challenging ocean environments. The specific objectives were as listed below:

- To develop strategies for conducting volumetric in-situ sensing surveys using multiple autonomous underwater vehicles (AUVs) in shallow waters.
- To develop methodologies and algorithms for adaptive sensing.
- To explore innovative methods for detection and classification of objects on the seabed.
- To engage students in research and STEM education in naval engineering

Two Remus 100 AUVs available at FAU were used for carrying out the effort, building on previous work. One of the AUVs was equipped with a magnetometer and the other with side-scan sonar to support conducting surveys of magnetic anomalies in the water column – with the magnetometer – and to follow up with detection and classification of associated acoustic signatures – with the side-scan sonar. Students were engaged in modeling and simulation, hands-on training with implementing sensors, and computer algorithms on AUVs and with AUV operations.

Students and FAU engineers on FAU's R/V McAllister during field-testing (2019).

Understanding Cybersecurity Implications of Using and Protecting Unmanned Aerial Vehicles

Professor: Mike Burmester, Daniel Schwartz

Technical Capability Alignment: Unmanned Systems Engineering & Integration, Autonomous Operations, Joint Interoperability and Common Control

Florida State University

This project began in May 2019 with two Computer Science faculty members, Mike Burmester and Dan Schwartz. Two students were recruited at that time, a master's student, and an undergraduate student. In July 2019, Dan Schwartz and William Goble attended NEEC Day in Newport, RI, and presented a poster describing the project. In August, four additional undergraduate students were recruited. Financial support for the students began at that time. Four of them are funded by the NEEC grant while two are funded by an NSA/DOD Capacity Building award (developing hands-on site scripting labs and learning materials). In spring 2020, one student will be funded by a Scholarship for Service grant that Mike has with the National Science Foundation but will continue working on the project as part of an FSU research project.

During this semester, to better understand the challenges of Unmanned Aerial Systems, the workload was divided into three main categories: a policy-based approach, a technical approach, and development of a plan to test the proposal. Each category was assigned to a two-person team. The first team focused on the policies and guidelines within CNSSP 28 and how the team's ideas met the requirements of the document. Throughout the semester, anytime that a new idea was proposed, they would check to make sure the project was following the policy guidelines and would assist in researching ideas for how to meet the project goals. In addition to studying what the guidelines were requiring, they would also perform any additional policy-based research, such as identifying approved encryption techniques that could be used for the project. Further, they also researched the various types of attacks that can occur on an unmanned aerial system.

Students discuss UAV types in a project to harden unmanned systems against cyber attacks.

NSWC Panama City

Collaborative Autonomous Maritime Vehicles for MCM Missions

Professor: Warren Dixon, Eric Schwartz

Technical Capability Alignment: MCM Detect and Engage Systems, Modular Mission Packaging, and Platform Integration and Handling

University of Florida

The University of Florida (UF) efforts are supported by two collaborative laboratories: the Nonlinear Control and Robotics Lab (NCR, http://ncr.mae.ufl.edu/index.php?id=ncr) and the Machine Intelligence Lab (MIL, www.mil.ufl.edu). The goal of the UF efforts is to investigate methods for collaboration between autonomous underwater and surface vehicles (AUVs and ASVs, respectively). 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 the 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.

Efforts in the NCR laboratory have focused on training graduate students to develop nonlinear estimation and control theories that determine the timing conditions for the relay and exploring agents to interact. Theoretical developments have been tested in preliminary experiments with mobile robots and quadcopters acting as the exploring agents and relay agent, respectively. Videos that demonstrate a wheeled mobile robot operating in a GPS-denied environment while being intermittently serviced with GPS information from a quadcopter are available at https://www.youtube.com/watch?v=89lCk7r9Q_M and https://www.youtube.com/watch?v=BUEQK3v4irA .

Because of the conservative nature of design and analysis on current control schemes, the dwell-time conditions from previous results are conservative, thereby degrading the robustness to intermittent feedback. Thus, an immediate goal is to develop dwell-time conditions that are less conservative.

Research on unmanned vehicles and the NEEC team.

The NEEC and NEEC students working on their project.

NSWC Philadelphia

A Computationally Efficient Shipboard Condition Prognostics System

Professor: Dr. Bin Zhang, Dr. Paul Ziehl

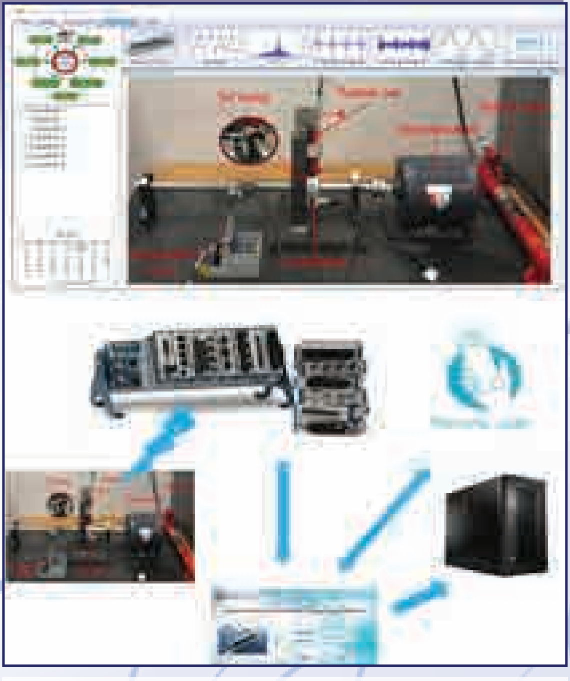
Technical Capability Alignment: PD13 Surface and Undersea Vehicle Machinery Automation, Controls, Sensors and Network Systems

University of South Carolina

Navy shipboard machinery systems are critical to accomplish military missions safely and reliably.

Traditional maintenance practices are labor intensive and can lead to unexpected downtime and increased operation and maintenance (O&M) cost. In an effort to provide a fast and effective assessment of the health condition and predict the remaining life of shipboard rotating machinery systems, this project aims to develop a low-cost distributed shipboard condition system (SCPS) that is enabled by sensing, data acquisition and analysis, feature extraction, fault dynamic modeling, diagnosis and prognosis, risk evaluation, and decision-making.

In the past project years, both Bayesian estimation methods and deep learning-data-driven methods were developed and integrated with a bearing test bed for real-time monitoring, and the work was extended to li-ion batteries. Four papers have been published based on findings from this project.



Framework of SCPS: test bed, data acquisition and storage, real-time signal processing and feature modeling, fault diagnosis and prognosis

Graduate student and undergraduate student working on the bearing degradation test bed which incorporates both an accelerometer and acoustic emission sensors.

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

Professor: Dr. Wei Xue and Dr. Robert R. Krchnavek

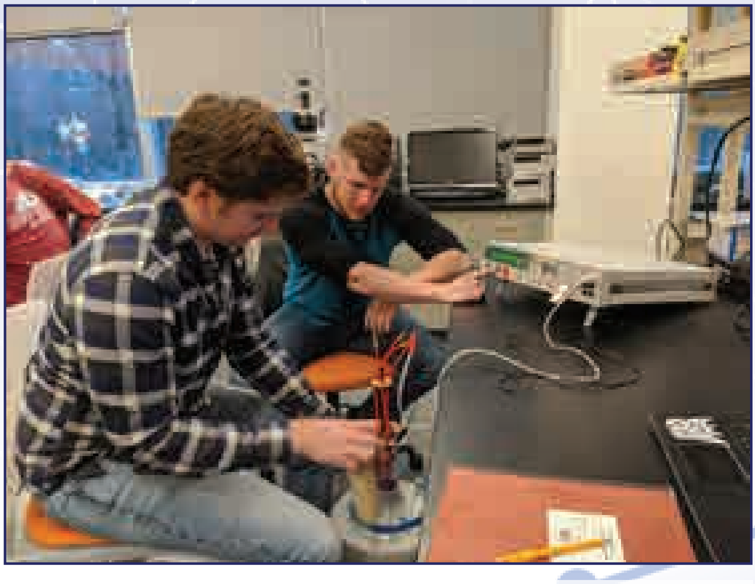
Technical Capability Alignment: PD10 Surface and Undersea Vehicle Electrical Power and Propulsion Systems

Rowan University

The research team at Rowan University is investigating advanced dielectric composites that can be used in cryogenic superconducting systems. The new materials will mimic the thermal behavior of the cable core element while maintaining high dielectric strength. Polymers and insulating nanoparticles are used to ensure the overall dielectric strength in the composites. Their thermal properties can create a complementary effect that results in composites with reduced thermal expansion coefficients. Currently, high-voltage breakdown tests are being performed to quantify the dielectric strengths of the new composites at various temperatures. Perforations formed during electrical breakdown are examined under microscopy to reveal the underlying failure mechanisms of the samples. The initial investigations on the thermal properties show that the composites have reduced thermal contraction rates from the pure polymer. The team is currently building a cryogenic circulation system to accommodate material characterization at cryogenic temperatures.

The new dielectrics will provide critical benefits, such as wider temperature windows, additional design flexibility, higher current density, and large power capacity for applied superconductor systems. They will be particularly useful in gas helium cooled high-temperature superconductor (HTS) cables on Navy ships. Further, this project has involved strong student participation at both graduate and undergraduate levels. It has provided substantial research work for more than 30 students within 2 years. 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 have prepared them for Navy-related jobs, with a number of students being employed by the Navy.

Rowan undergraduate students running simulations on the cryogenic testing chamber.



Rowan graduate students conducting dielectric breakdown experiments in liquid nitrogen.

NSWC Philadelphia

Networked Multi-Converter Power System Instrumentation and Measurement Analysis

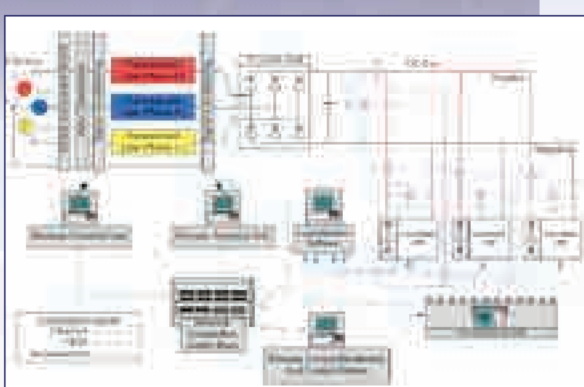
Professor: Dr. Karen Miu Miller and Dr. Jaudelice de Oliveira

Technical Capability Alignment: PD13 Surface and Undersea Vehicle Machinery Automation, Controls, Sensors and Network Systems

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. When operating such a system, questions arise: We expect it to be better, but how much better? What are its limits?

Supervisory control of all-electric shipboard power systems will require a better understanding of the underlying instrumentation and measurement systems. The second period of this effort has focused on understanding communication system delay characteristics and multiple converter control actuation characteristics in multi-node power systems. In particular, software simulations of communication delay patterns were conducted under varying packet sizes and sending rates using common types of power system data. AC/DC microgrid hardware experiments were conducted to observe and quantify control actuation times as well as to capture uncertainty in actuation start times for static and dynamic loads. It is shown that measurable differences in control actuation times are experienced even when utilizing multiple power electronic loads of the same type and from the same manufacturer. In addition, these actuation times are of the same order of magnitude in simulated communication delays. Hence, the interplay of measurement data and control data must be considered and properly designed for cyber-physical power systems.



Flow diagram of the AC/DC microgrid hardware laboratory: e.g., one test rack setup.

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 are developed by graduate students.

NSWC Port Hueneme

Developing MANDRAKE: a Maintenance AND Remediation Anticipatory Knowledge Environment

Professor: Dr. Rich Wolski

Technical Capability Alignment:
PH01 Strike Force Interoperability and Theater Warfare Systems ISE, T&E, and IPS

University of California, Santa Barbara

Mandrake is a software infrastructure for edge clouds (private clouds located at the network edge), designed to provide reliable, "lights out" unattended operation and application hosting in Internet of things (IoT) deployments. Specifically, Mandrake is a system for automatically recovering from failures in small edge clouds without human intervention. The Mandrake prototype is shown in figure 1. Self-managing edge systems are critical for remote deployments (e.g., on ships), which require disconnected operation and the ability to make progress (perhaps with degraded performance) until maintenance is possible. Mandrake implements reliable private cloud operation in restricted resource environments and data durability features that hosted applications can leverage. Mandrake is leveraged here for hosting remote Hadoop applications at the edge. Empirical evaluation shows that Mandrake is able to ensure Hadoop's data durability guarantees efficiently in the presence of relatively frequent failures even when resources are scarce.

As depicted in figures 2 and 3, when a failure occurs, the Mandrake Coordinator (MC) reallocates resources to fit user-defined goals, allowing for continued operation at degraded performance (but not degraded functionality). The Mandrake Application Orchestrater (MAO), running on the provisioned virtual machines (VMs), manages the application configuration changes needed to continue operation in the face of system configuration changes (in place of a human administrator). With Hadoop as a case study, it was demonstrated that the collection of services introduces little overhead compared to "native" Hadoop execution. Furthermore, Mandrake can resiliently place and balance data in the Hadoop File System (HDFS) with only minor slowdowns and without modifying Hadoop.

Figure 1: The Mandrake edge cloud, consisting of nine Intel NUC6i7KYK NUCs and a Netgear GS116 gigabit switch.

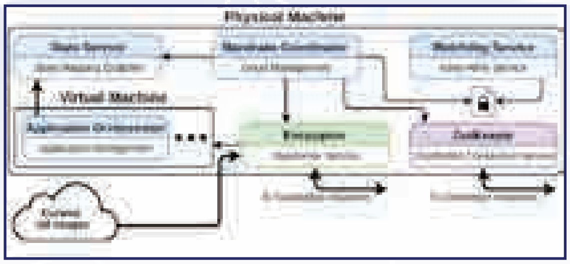


Figure 2: A physical machine with its collection of services composing Mandrake's control plane. The Watchdog monitors the Mandrake Coordinator (MC) and restarts it if it fails. The MC submits its mapping to the State Service, which can then be queried by submitting its mapping to the State Service, which can then be queried by the Mandrake Application Orchestrator (MAO) running in each VM. In the current prototype, Zookeeper is used for distributed consensus and Eucalyptus is used for VM provisioning.

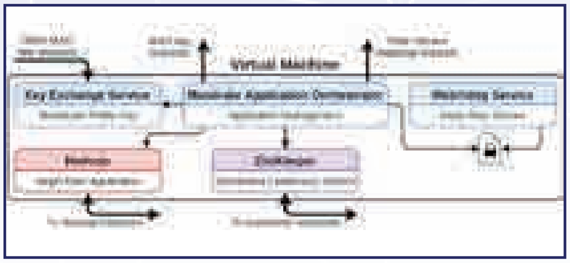


Figure 3: A virtual machine with its collection of services. The Watchdog monitors the MAO and restarts it if it fails. A key exchange service fields HTTP requests from other MAO instances for public SSH keys, bootstrapping communication. MAO fetches the cloud view from the State Service running on the MC leader's physical machine. Zookeeper implements distributed consensus across VMs.

NSWC Port Hueneme

Assisted Real-Time Maintenance Operations in Augmented Reality (ARMOR)

Professor: Dr. Aaron Elkins, Dr. Bongsik Shin

Technical Capability Alignment: PH08 Radar Systems ISE, T&E, and IPS

San Diego State University

Artificial intelligence (AI) researchers at San Diego State University are investigating how to support the Navy's In-Service Engineering Agent (ISEA) of the Future with augmented reality (AR). The Assisted Real-Time Maintenance Operations in Augmented Reality (ARMOR) system is currently under development and integrates AR equipment (e.g., HoloLens) with computer vision-based AI technology to provide real-time support through the overlaying of the current maintenance task status, location, and instructions/references over their field of view from inside an AR headset.

The researchers have recently kicked off work on this project and have acquired the hardware, set up the development environment, prototyped AR interfaces, and begun designing the software that will integrate the AR and AI technologies. The next steps in the research will be to work with Navy stakeholders to identify the requirements and maintenance activities to support with ARMOR. These maintenance activities will be "taught" to AI algorithms (e.g., identify equipment type) and integrated into the ARMOR system used by ISEA.

SDSU Researchers Demonstrating AR Interface Prototype to Port Hueneme team.

NSWC Port Hueneme

Computer Vision-Based Intelligent Assistant for Mistake Proofing of Complex Maintenance Tasks on Navy Ships

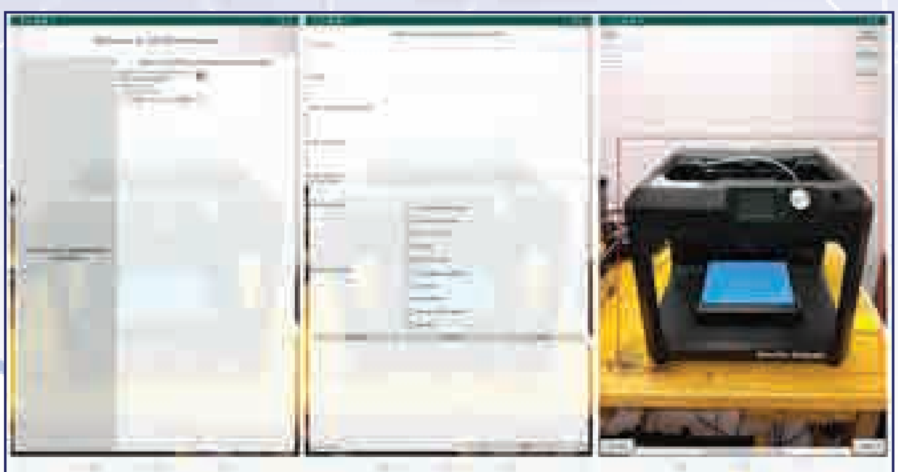
Professor: Dr. Rahul Rai

Technical Capability Alignment: PH08 Radar Systems ISE, T&E, and IPS

New York State University at Buffalo

The proposed project aims to create a robust and intuitive system to aid maintenance personnel in performing maintenance tasks onboard Naval ships. The current methods for performing maintenance depend on paper manuals and user experience, which are inefficient and unpredictable. This project's maintenance solution incorporates augmented reality and machine learning to aid users of every experience level in performing maintenance on a system.

This 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 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 creates a unique, impactful, and innovative solution for performing maintenance.



Screenshots of the prototype interface for choosing a maintenance procedure, creating a new procedure, and performing a procedure.

Graduate and undergraduate students participating in work on the COVIA project.

NSWC Port Hueneme

Atmospheric Turbulence Generation in Multiphase Flows with Density Stratification and Phase Change

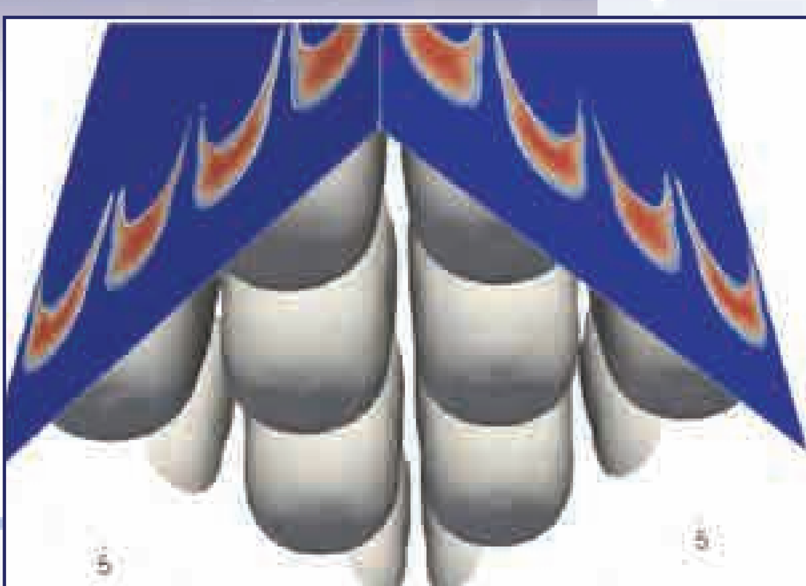
Professor: Dr. Eckart Meiburg

Technical Capability Alignment:
PH04 Underway Replenishment Systems ISE, RDT&E, and IPS

University of California, Santa Barbara

The Naval Surface Warfare Center, Port Hueneme Division, is the in-service engineering agent for the U.S. Navy Fleet's combat, communication and radar systems. A greater understanding and improved modeling of atmospheric turbulence at various heights is critical to not only the performance of systems but also to understanding the maintenance and logistics requirements. The research conducted under this NEEC program will help in the test, evaluation and support of fielded and future systems.

The first step is to investigate how settling and phase change can combine to drive an instability, as a simple model for the formation of mammatus clouds. The idealized system consists of a layer (an "anvil") of air mixed with saturated water vapor and monodisperse water droplets, sitting atop dry air. The water droplets in the anvil settle under gravity due to their finite size, evaporating as they enter dry air, and cooling the layer of air just below the anvil. The colder air just below the anvil thus becomes denser than the dry air below it, forming a density "overhang," which is unstable. The strength of the instability depends on both the density difference between the density overhang and the dry ambient, and the depth of the overhang. Using linear stability analysis and nonlinear simulations in one, two and three dimensions, a study of how the amplitude and depth of the density layer depend on the initial conditions finds that their variations can be explained in terms of the size of the droplets making up the liquid content of the anvil and by the total amount of liquid water contained in the anvil. The size of the water droplets is the controlling factor in the structure of the clouds: mammatus-like lobes form for large droplet sizes. Small droplet sizes lead to a "leaky" instability resulting in a stringy cloud structure resembling the newly designated asperitas.



NSWC Port Hueneme

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

Professor: Dr. Tobias Hollerer

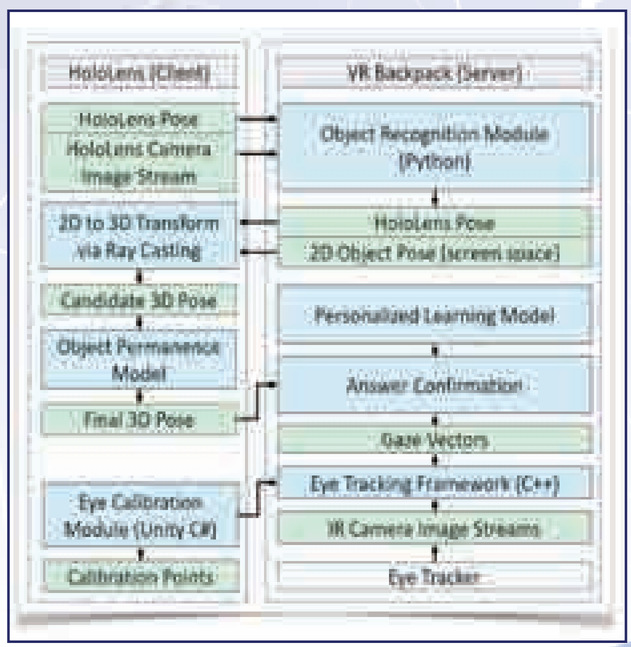
Technical Capability Alignment:
PH04 Underway Replenishment Systems ISE, RDT&E, and IPS

University of California, Santa Barbara

The objective of this project is to research a tracking and registration methodology that, in a complementary fashion, models and maintains a hybrid model of a tracking environment, and utilizes machine learning for geometric and semantic modeling of key environment objects.

The project's mobile augmented reality (AR) devices (currently: Microsoft Hololens for head-worn AR, and Apple ARKit for hand-held devices) work in conjunction with an environment and modeling server implemented and deployed as part of the local stand-alone mobile device (see the system architecture in the figure below (right).

During the first 6 months of this effort, the team consisted of the PI and student researchers who were supervising four undergraduate researchers and, during the summer, as part of an outreach program, four competitively selected high-school students to work at the intersection of computer vision and machine learning. The work with one of these students resulted in an environment and model server architecture, an extended literature review of relevant state-of-the-art technologies, and a mapping out of the planned approach that denoted decision points and alternatives. The team also worked on AR user interfaces for switching among different maintenance-oriented tasks related to recognized objects and on the eye tracking framework to monitor attention to such AR material presented to the user (see the figure below (left).



AR overlays on automatically recognized objects on the Hololens (left), and system architecture for the planned AR equipment maintenance application (right).

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