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FY21 CRUSER Seed Research Program (SRP)
Tier 1 & 2 Selects
Nov 2020

Dr. Brian Bingham, Dir.
bbingham@nps.edu | (831) 656-2396

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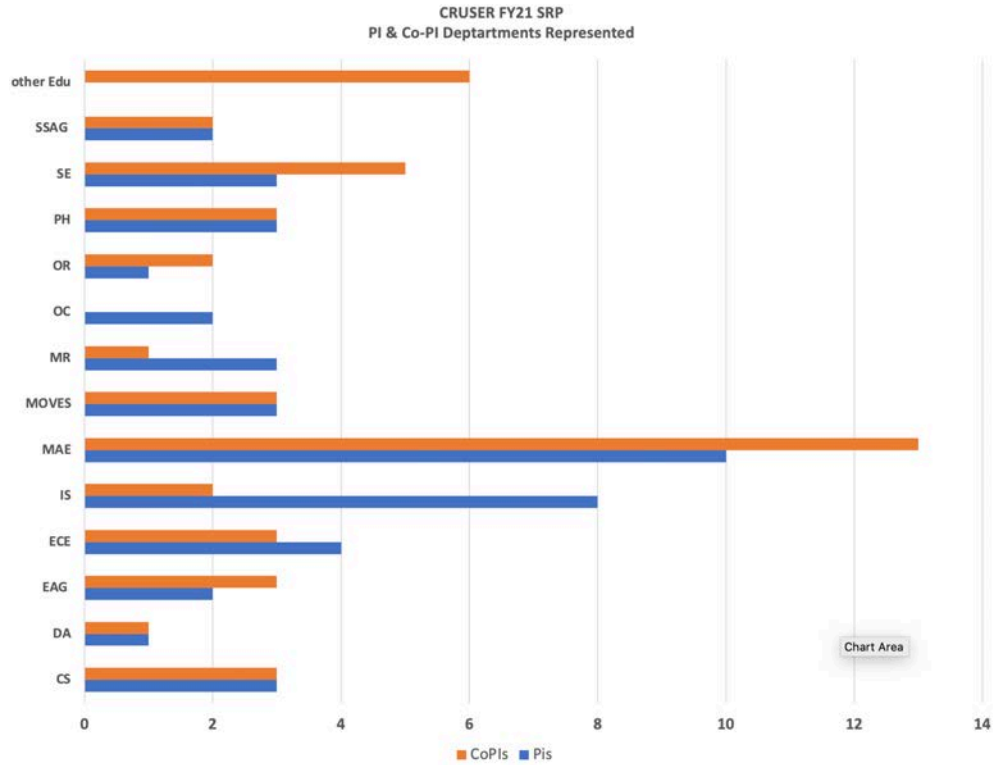
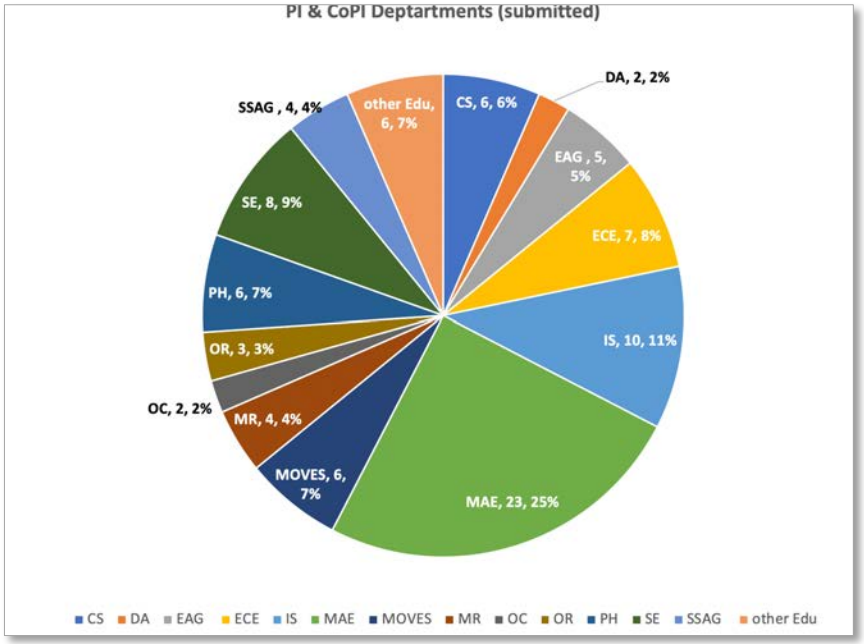
FY21 Seed Research Proposal Overview

# Proposals	44
Departments Represented	62% (13/21)
Total Funding Requested	$7,144,242
New Research	33 (73%)
Continuation	12 (27%)
Current/pending Support	7 (16%)

Professor	8	15.69%
Associate Professor	13	25.49%
Assistant Professor	6	11.76%
Research Professor	4	7.84%
Research Associate Professor	3	5.88%
Research Assistant Professor	4	7.84%
Professor of Practice	0	0.00%
Faculty Associate Research	11	21.57%
Other	2	3.92%

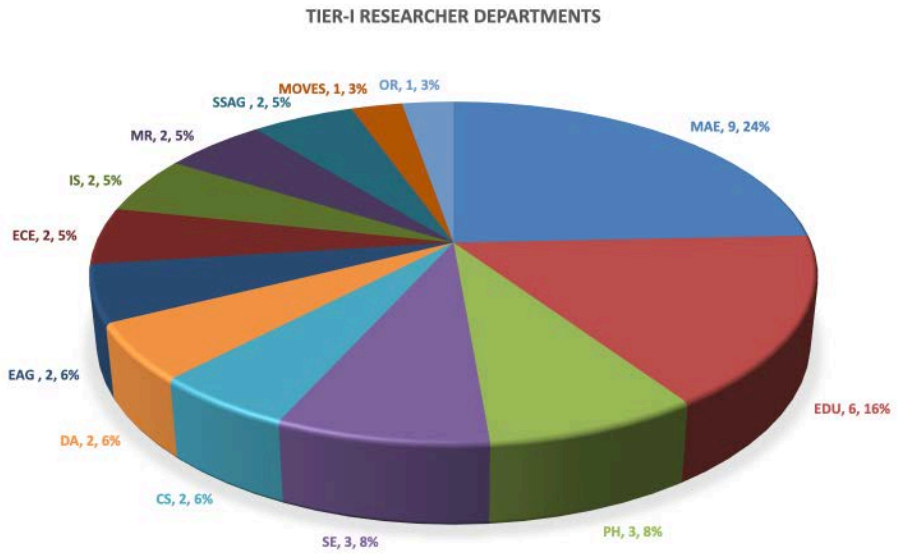




Tier I & II Selects

TIER I

#	PI	Dept	C0-PI(s)	Proposal Title
1	Blanken	DA	Davis (DA)	COTS Unmanned Systems and Partner Force Innovation
2	Brophy	MAE	Codoni (MAE)	Counter Aerial UxS Munition Delivery System
3	Brutzman	IS	Blais (MOVES)	Ethical Control of Unmanned Systems: Repeatable Mission Evaluation Through Unmanned Systems Data Strategy for UMAA/RAIL
4	Canan	IS	Demir (ASU)	Communication Dynamics of Human-Machine Teams in Context Sensitive Battle-Field Environment
5	Clark	PH	Kaminer (MAE)	Developing operational planning simulations for defense against attacking drone swarms
6	Davis	CS	Jones (MAE) Giles (SE)	Expediting Swarm System Development with High Fidelity Live/Virtual Modeling and Simulation
7	Fletcher	EAG	Hahn (EAG)	Priority Legal and Policy Issues of UxS
8	Horner	MAE	Yoshida (OR) Xie (CS)	Behavior Automation for UxV Networked Control Systems
9	Jones	MAE	Dobrokhodov (MAE) Smith (PH) Leary (PHY)	Aqua-Quad Vector Sensor Integration and Participation in Trident Warrior 2021
10	Kragelund	MAE	Kaminer (MAE)	Hybrid USV Attacks for Counter-Swarm Experimentation
11	Newman	SSAG	Minelli (SSAG)	Predictive Failure Analysis for Autonomous Networked Ground Stations
12	Van Bossuyt	SE	Semmens (SE) Fletcher (EAG) Weger (UAH) Mesmer (UAH) Tenhundfeld (UAH) Jones (UAH)	Formation, Implementation, and Verification of Requirements for Human-Autonomy Teaming
13	Wang	MR	Yamaguchi (MR)	sUAS-based Environmental Sampling in Support of High Energy Laser Weapon Systems
14	Yun	ECE	Calusdian (ECE)	Localization of Unmanned Ground Systems Using the Zero Velocity Update Technique and a 3-D LiDAR in the Absence of GNSS
15	Yakimenkop	MAE		Enhancing c-UAS Capabilities using a 3D LiDAR



TIER II

#	PI	Dept	C0-PI(s)	Proposal Title
1	Dobrokhodov	MAE	Craparo (OR) Jones (MAE)	Energy-Aware Aerial Logistics in Support of USMC EABO operation
2	Eldred	SE	Pollman (SE)	WIEVLE – Development and Testing of a Spherical AUV Platform
3	Joseph	OC		Drifting with Direction
4	Kartalov	PH		3D-Printed Artificial Muscles Optimization through Experimental Prototyping and COMSOL Simulations, to Enable Quiet Propulsion and Acoustic Translucence of UUVs
5	Leary	PH	Smith (PH)	Persistent Mobile Acoustic Surveillance and Autonomous Target Motion Analysis from a Wave Glider USV
6	Miller	IS	McGuire (IS)	Providing Interdependence Analyses for USMC Future Vertical Lift and Human Teaming
7	Prince	CS	Singh (CS)	Autonomous Aerial Damage Assessment

Arizona State Univ. (ASU) | Computer Sci. (CS) | Defense Analysis (DA) | Energy Academic Group (EAG) | Electrical & Computer Engineering (ECE) | Information Sciences (IS) | Mechanical & Aeronautical Engineering (MAE) | Meteorology (MR) | Modeling & Virtual Environments Simulation (MOVES) | Oceanography (OC) | Operations Research (OR) | Physics (PH) | Systems Engineering (SE) | Space Systems Academic Group (SSAG) | Univ. Alabama Huntsville (UAH)

FY21 Research Themes

Four Seed Research Themes Solicited [selected]

1. Autonomy and Modeling & Simulation (M&S) [1]
2. Autonomy Enabled Ocean Science [2]
3. Autonomy in Context [5]
4. Autonomy at Large (all others) [6]

Autonomy and M&S

Autonomy and M&S

1. **Autonomy Modeling and Simulation (A-M&S)**
   New technologies, process and infrastructure to support the vision of rapidly integrating, testing, and deploying autonomy software.
   a. Possible research topics might include:
      i. Authentic simulation of mobility (vehicles), perception (sensors) and environments in relevant operational environment/scenarios in real-time and faster-than-real-time.
      ii. Methods and limitations of employing cloud infrastructure for development, testing and deployment of autonomy – and to support robotics education.
      iii. Automated test case planning/execution and test data reduction and analysis to support SWIL and HWIL performance evaluation and T&E.
      iv. Rapid virtual environment creation from real sensor data.
      v. Discoverable models for mobility and perception for autonomy
      vi. Common interfaces including common control system (CCS) interfaces and unmanned maritime autonomy architecture (UMAA)
      vii. Methods and limitations for simulation-to-real transfer learning in marine environments.
   b. Alignment and possible collaboration/transition partners: PMS 406 and Rapid Autonomy Integration Laboratory (RAIL)

Autonomy and M&S

Expediting Swarm System Development with High Fidelity Live/Virtual Modeling and Simulation

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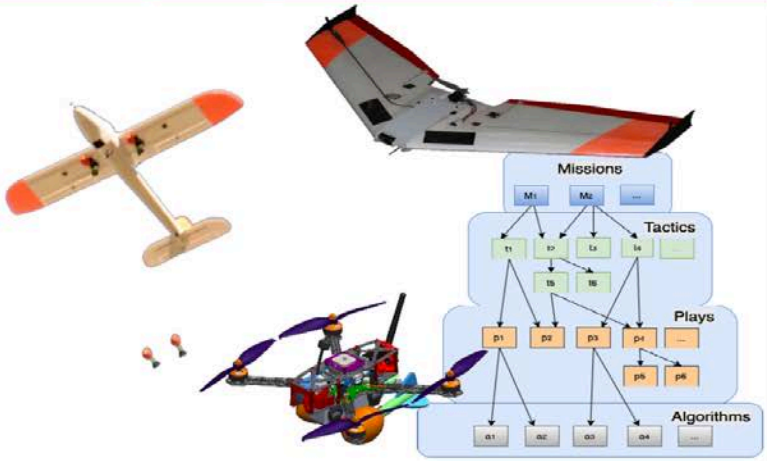


Problem Statement

- Current multi-vehicle system architectures support neither meaningful operator oversight nor rapid capability development
- Proposed Solution
  - Improved fidelity of physically-based simulation models
  - Faster-than-real-time simulation supporting more exhaustive testing
  - Mission-focused, top-down capability development

Impact

- Autonomy M & S
  - Improved fidelity of physically-based simulation
    - Simulation results more likely to align with real world
    - Realistic mixed live/virtual experimentation
  - Faster-than-real-time simulation
    - More exhaustive testing (e.g., Monte Carlo)
- Autonomy in Context
  - Top-down, composable capability development
    - Allows both developers and operators to focus on mission
    - Facilitates effective operator oversight

Transition

- Potential Follow on Sponsors
  - Office of Naval Research
  - Marine Corps Warfighting Laboratory

Seed Research Program 2021

PI: Dr. Duane Davis
Email: dtdavi1@nps.edu
Phone: 831-656-2239

Co-PIs: Dr. Kevin Jones
CDR Kathleen Giles, USN, PhD

Tier I

Autonomy Enabled Ocean Science

Autonomy Enabled Ocean Science

2. **Autonomy Enabled Ocean Science**

   Robotic and autonomous systems have a critical role in ensuring that the U.S. Navy maintains a competitive advantage in its ability to understand and exploit the ocean environment.

   a. Possible research topics might include:

      i. Adaptive in-situ sensing from mobile platforms to improve inference of ocean/acoustic properties.

      ii. Autonomous payload data-driven mobility methods to leverage novel UxS platforms for synoptic environmental estimation, e.g., environmentally-influence autonomous mission planning and execution, planning tools for persistent, autonomous operations that optimize environmental impacts.

      iii. In-situ environmental modeling aboard UxS to lower navigation uncertainty, reduce energy consumption or reduce environmental estimation uncertainty.

      iv. Adaptation of environmental models (oceanographic, meteorological, acoustic) to support A-M&S. E.g.,

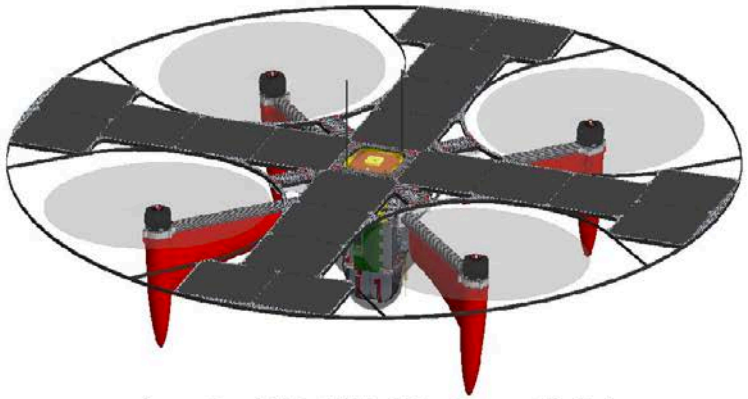
         1. Adaptation of acoustic scattering models to the simulation of high-frequency sonar sensor models to simulate sub-sea perception in real-time within UUV mobile manipulation scenarios
         2. Authentic ocean current models for HWIL/SWIL simulation of underwater glider operations faster than real-time.
         3. Faster than real-time simulation of acoustic navigation and communication within generalized operational areas for UUV performance evaluation via simulation.

   b. Alignment and possible collaboration/transition partners:

      ONR Task Force Ocean, specifically the Department Research Initiative (DRI).

Autonomy Enabled Ocean Science

Aqua-Quad Vector Sensor Integration and Participation in Trident Warrior 2021 (FOUO)



Aqua-Quad Hybrid Mobility Concept Vehicle

Problem Statement

- Final push in several key technology areas:
  - Flight controls and autopilot sensor evolution
  - Autopilot modifications for flight off water
  - Integration of the acoustic sensor and DAQ
  - Flight characterization with slung payload
  - Integration of ruggedized solar array
- Rigorous flight schedule to meet T&Os for Trident Warrior participation

Impact

- Provides capability for autonomous, long-endurance, remote sensing in ocean environments, including:
  - Collaborative, passive acoustic sensing for precision tracking of underwater targets
  - Adaptive in-situ sensing from mobile platforms
  - Autonomous payload data-driven mobility
  - In-situ environmental modeling

Transition

- Collaborative efforts with a team at NUWC Keyport will expand, with a goal of sensor integration and participation in Trident Warrior 2021
- Increase TRL to a point where Aqua-Quad can reasonably be transitioned to Navy labs and industry partners

UNCLASSIFIED//FOUO

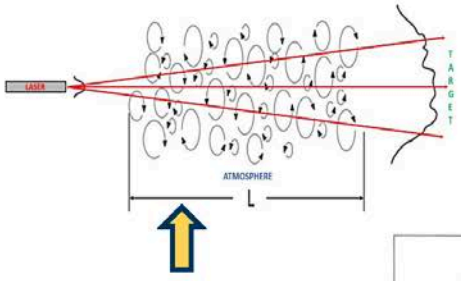
Seed Research Program 2021

PI: Kevin Jones, Mechanical and Aerospace Engineering Department
Co-PI: Vladimir Dobrokhodov, MAE, Paul Leary, PH, Kevin Smith, PH

Tier I

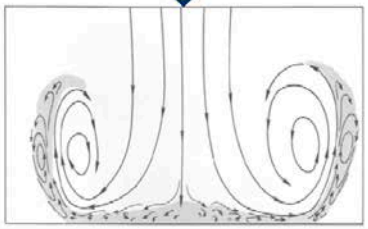
Autonomy Enabled Ocean Science

sUAS-based Environmental Sampling in Support of High Energy Laser Weapon Systems (HELWS)



Turbulence in the atmosphere and high energy laser wave front deformation

Propwash of multicopter sUAS affecting the atmospheric turbulence field for low-level flights.



Problem Statement

- We propose developing an optical turbulence sensing capability for multicopter sUAS.
- Differential temperature sensing methods will be adapted to quantifying temperature structure parameters from sUAS. Iterative testing for sensor placement will help mitigate impacts of propwash on turbulence sensing.
- We will identify the potential and limits of using multicopter sUAS for optical scintillation measurements and develop optimal strategies for sampling the undisturbed atmosphere.

Impact

- The new sUAS-based sampling capability greatly increases the potential of obtaining a large amount of data needed to improve our capacity to predict atmospheric optical turbulence.
- Real time data support are made possible by the sUAS–based measurements in support of HELWS operations.
- The system will be tested against similar measurements from towers and possibly fixed-wing sUAS to ensure the sensor performance and the appropriate sampling strategy.

Transition

- Sampling of optical turbulence close to the beam director and along the HEL propagation path are critical information to the warfighters for on-scene, short-time performance prediction.
- Continued support may come from multiple sources, e.g., ONR and Joint Directed Energy Transition Office (DEJTO).
- Extensive collaborations with various Navy HELWS test and evaluation programs such as SSL-TM and HELIOS are ongoing and will continue.

Seed Research Program 2021

PI: Qing Wang, Meteorology Department
CoPI: Ryan Yamaguchi, Meteorology Department

Tier I

Autonomy in Context

Autonomy in Context

3. **Autonomy in Context**
   Putting the S&T advancements to operational use requires that our human-machine teaming, policy, law, ethics and acquisition capabilities adapt to the unique opportunities and challenges of UxS.
   a. Possible research topics might include:
      i. Ethics employment and planning for UxS operations
      ii. Mixed manned/autonomous systems with sharing/borrowing/transfer of autonomous assets across naval/expeditionary missions, domains, and warfighters
      iii. Joint learning and training between humans and autonomous systems
      iv. Optimizing task and function allocation and the human-autonomy relationship including understanding the appropriate role/function of humans and mapping to context and environment
      v. Understanding what humans need to form trustable mental models of AI/autonomy elements
      vi. Acquisition
      vii. Applicability and interpretation of Law of the Sea, Law of Armed Conflict and Salvage at Sea to international Law, U.S. Law and DoD policies that pertain to weaponized UxS.
      viii. Analysis of environmental policy and law to address new considerations with the use of expendable UxS.
      ix. Policy and law to establish who will be held accountable for intended and unintended consequences resulting from the use of UxS. (such as unintended damage.

Autonomy in Context

COTS Unmanned Systems and Partner Force Innovation

COTS Innovation for Partner Forces

Problem Statement

- How can SOF contribute in Great Power Competition (GPC)?
- How can innovation be used as a partnering tool for SOF?
- How can cheap, sustainable unmanned systems get into the hands of partner forces?

Solution:

- The development of SOF programs for "COTS innovation" with partner forces.

Impact

- Develop an updated role for SOF in GPC
- Provide a cheap way to compete with PRC in partner force relationships
- Empower innovation bases in partner societies
- Provide tangible solutions to partner force challenges while building enduring relationships

Transition

- USSOCOM is seeking creative avenues for SOF contribution to GPC
- USASOC and NSW are actively seeking updated methods to build enduring, relevant relationships with partner forces
- Goal: To interest these organizations in this concept and posture NPS to provide the necessary professional development

Seed Research Program 2021

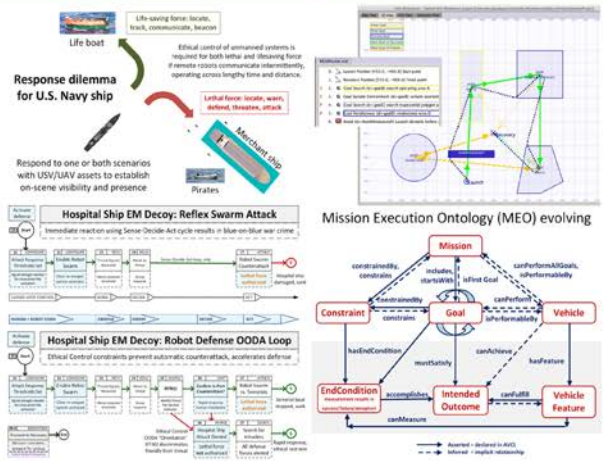
PI: Leo Blanken, Defense Analysis Department
Co-PI: CDR Justin Davis, Naval Special Warfare Chair

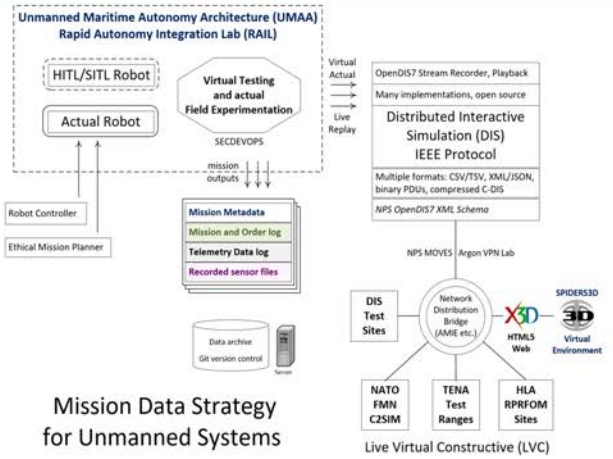
Tier I

Autonomy in Context

Ethical Control of Unmanned Systems: Repeatable Mission Evaluation Through Unmanned Systems Data Strategy

CRUSER Consortium for Robotics and Unmanned Systems Education and Research





Mission Data Strategy for Unmanned Systems

Live Virtual Constructive (LVC)

Why / Objectives

- Ethical control of unmanned systems can be accomplished through structured mission definitions that are trusted, consistently readable, validatable, repeatable and understandable by humans and robots.
- Orders must be lawful. Unmanned systems must behave ethically and comprehensibly if they are to support manned military units effectively.
- Well-structured mission orders can be tested and trusted to give human commanders confidence that offboard systems *will do what they are told to do*, and further *will not do what they are forbidden to do*.
- Demonstrate that no technological limitations exist that prevent applying the same kind of ethical constraints on robots and unmanned vehicles that already apply to humans, in lethal and life-saving scenarios.

https://savage.nps.edu/EthicalControl

What / Deliverables

- Unmanned Systems Data Strategy is fundamental need for progress, otherwise all experiments (real or virtual) are unrepeatable, transient.
- Mission orders, metadata, track telemetry and sensor records together provide repeatable archiving of robot system testing for live-virtual-constructive (LVC) reuse, for replay live or rehearsal analysis.
- Update Mission Execution Ontology (MEO) concepts demonstrated in tests and simulation, building to perform field experimentation (FX).
- Define, simulate, and test combination of real-world goals and ethical constraints to robot mission tasking across set of canonical scenarios.
- Illustrate how human-robot teams meet moral and legal requirements if deploying unmanned systems with potential for lethal, life-saving force.

Building on Simulation, Experimentation

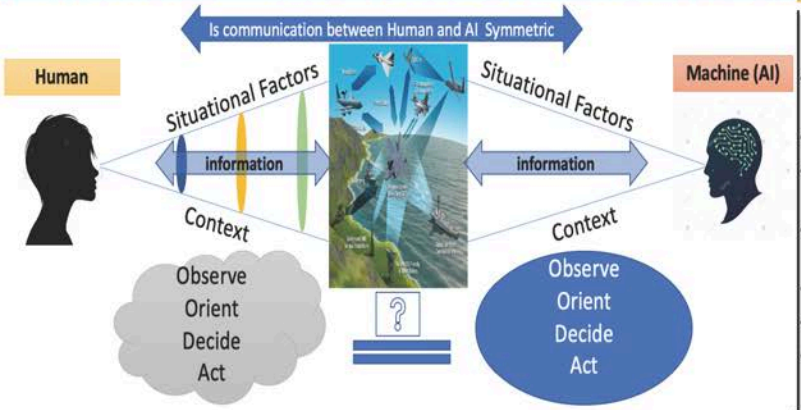
Principal Investigator: Don Brutzman brutzman@nps.edu 1.831.656.2149
Co-Investigator: Curtis Blais clblais@nps.edu 1.831.656.3215

Tier I

Autonomy in Context

Communication Dynamics of Human-Machine Teams in Context Sensitive Battle-Field Environment

CRUSER Consortium for Robotics and Unmanned Systems Education and Research



Human vs AI perceiving the same situation.

Problem Statement

- AI systems are employed to enhance warfighting capabilities in the form of Human Machine Teams (HMTs).
- AI mimics human behavior and designed with the rules of classical/Boolean logic.
- But human judgments do not always obey classical logic; in context sensitive situations, information processing and communication are subject to order effects.
- Our approach will study communication dynamics of HMTs with a mathematical and experimental method that address the limitations of the Boolean logic
- The theoretical aspect will capitalize on the quantum models of cognition.
- Categorization-Decision experiment will be conducted with time compression.
- The communication dynamics will be tested w/ and w/o machines. Sender/receiver perspective will be included as pull and push information environment.
- Our approach will use the OODA loop framework to compare decision making processes of the human and machine teammates.

Impact

- While leveraging the faster information processing capabilities of machines, , inadvertent over reliance via frequent communication can introduce mission critical vulnerabilities.
- This work is critical to understand and develop solutions to these type of vulnerabilities.
- This work is critical to understand communication dynamics in HMTs and findings will be used to better integrate and employ machine teammates via HMTs to enhance warfighting capabilities.
- The effect of the difference between human-human, human-machine communication will be measured in the experiment.
- To measure the success, the findings of the experiment will be submitted to Computer in Human Behavior journal and presented to DoD Human Factors community at DoD HFE TAG.

Transition

- Military Sealift Command (MSC) has already initiated collaboration efforts to integrate a synthetic team to their decision process. This effort is a joint effort with NPS, Old Dominion University and MSC.
- Air Force Research Lab , 711th Human Performance Wing research scientists collaborates in extended work to understand team behavior in cyberspace.
- Arizona State University and Old Dominion University are collaborating with Naval Postgraduate School for advanced research program to integrate synthetic teammates into the decision process.
- One of the leading autonomous system research program is Goal-Driven autonomy; this research involves goal-seeking/rebel agents which can communicate with humans. The findings of this work can be used in this program.

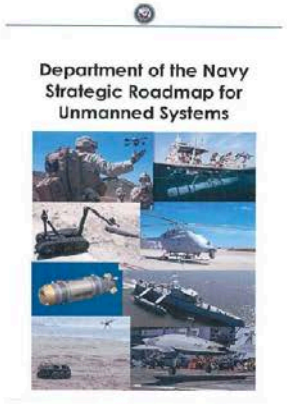
Seed Research Program 2021

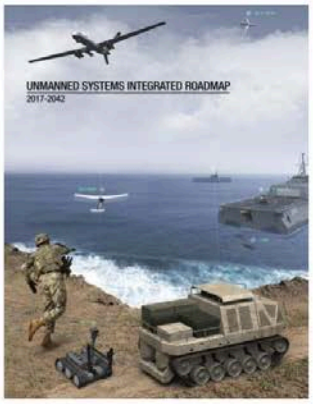
PI: Dr. A. Mustafa Canan, IS NPS, anthony.canan@nps.edu
Co-PI: Dr. Mustafa Demir, Ira A. Fulton Schools of Engineering, Arizona State University, mdemir@asu.edu

Tier I

Autonomy in Context

Priority Legal and Policy Issues of UxS





DoD and Navy Strategies call for law and policy analysis to advance US legal and ethical development and use of UxS.

Problem Statement

- DoD and the Navy consistently call for law and policy research and analysis to address legal and policy issues of UxS, especially as complex technology and operational environments evolve.
- Project will:
  - prioritize legal and policy issues related to design, development and military use of UxS;
  - analyze US and international law to provide thorough understanding of the existing and emerging legal frameworks;
  - answer specific legal questions and fill in policy gaps.
- Researchers will work collaboratively with US and international experts and analyze caselaw, statutes, treaties and official policies (directives/instructions).

Impact

- Results support research by answering law and policy questions that can facilitate more effective platform design and appropriate testing and use of UxS.
- Findings will assist warfighters to address requirements within the operational, liability, and environmental contexts, including NPS students who will contribute to research and analysis.
- Success will be in delivering confident and thorough results to legal and policy questions and aiding the design of Navy and DoD policies which will positively impact Fleet effectiveness.

Transition

- Law and policy issues are consistently identified as priorities within the Navy's UxS Campaign Plan and DoD Unmanned Systems Strategy.
- Research will contribute to the work of the DASN RDT&E and CNR Intelligent Autonomous System (IAS) Strategic Development Team (SDT) and the Policy and Ethics Pillar (being stood up through ONR). Future support is anticipated to address continuing law and policy needs and analysis.
- Researchers will submit findings to support the CNO's UxS Campaign Plan, participate in the Policy and Ethics Pillar and seek support through international partnerships (including TTCP) to ensure legal and ethical use of UxS.

Seed Research Program 2021

PI: Kristen Fletcher, Energy Academic Group
Co-PI: Eric Hahn, Energy Academic Group

Tier I

Autonomy in Context

Formation, Implementation, and Verification of Requirements for Human-Autonomy Teaming

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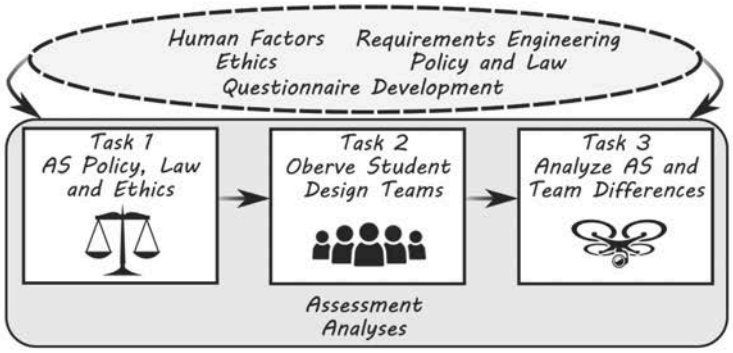


Proposed Research Tasks

Problem Statement

- Investigate the formation, implementation, and verification of requirements for autonomous systems, systems which have inherent uncertainties that challenge the static nature of requirements.
- Investigate current and future policies and laws that may impact autonomous systems requirements engineering, including ethical aspects.
- Develop a novel human study to observe UAH and NPS student design groups
- Develop a toolset to aid in the engineering of autonomous systems requirements for human-autonomy teaming.

Impact

- **Research Impact**: Technical report and/or one or more journal manuscripts discussing the human study and the investigation into current and future policies and laws that will impact autonomous systems requirements engineering; Reusable design team experiment, questionnaire, and semi-structured interview on design teams;
- **Warfighting Impact**: Evidence of the formation, implementation, and verification of autonomous systems requirements; Identification of approaches to aid in requirements engineering. Findings toolset will be directly applicable to DON systems and design engineers.
- **Assessment**: Rigorous statistical and engineering analyses

Transition

- Supports the "Autonomy in Context" CRUSER FY21 theme and incorporates topic areas of ethics, policy, and law.
- The internal (NPS: Systems Engineering and Policy/Law) and external collaborative team (UAH: Systems Engineering, Psychology, and Philosophy) will leverage the work performed here to propose for multi-year ONR and multi-year Army CCDC funding, working with Army leaders at UAH-Army Center.
- Follow-on topics: Validating simulations to be used during AS requirement development; Studying the warfighters' interactions with AS on the battlefield to improve testing of requirements; Development of novel verification processes for dynamic system performance.

Seed Research Program 2021

PI: Douglas L. Van Bossuyt, Systems Engineering
Co-PI: Kristen Fletcher, Energy Academic Group
Co-PI: Robert Semmens, Systems Engineering
PI: Kristin Weger, Psychology
Co-PI: Bryan Mesmer, Systems Engineering
Co-I: Nathan Tenhundfeld, Psychology
Co-I: Nicholaos Jones, Philosophy

Tier I

Autonomy in Context

Interdependence and Trust in USMC Future Vertical Lift (FVL) Operations

CRUSER Consortium for Robotics and Unmanned Systems Education and Research

Candidate FVL

Problem Statement

- FVL operates in several flight regimes, from fully manned to fully automated, in support of missions. Human machine teaming (HMT) options abound.
- Researchers conduct an interdependence analysis (IA) on a representative flight regime-mission combination to define HMT challenges.
- Researcher use the IA to draft a trust development plan for FVL HMT
- Approach is technical reviews, SME interaction, using IA tools, and employing trust development concepts.

Impact

- Research will reveal common FVL HMT challenges, define priorities for interaction research investment, establish a method for repeatable IAs for different mission flight regime combinations, and embed trust up front part of the overall design process.
- USMC's ambitious concept, dependent on building resilient and reliable workflows that are automated, manual, and flexible, will deliver enhanced combat effectiveness.
- Measured by increased reliance and acceptance.

Transition

- USMC HQ Aviation is most interested in this research and seeks further resources to continue next FYs.
- They are also interested in modeling these interactions in a life, virtual, constructive environment such as MOVES can provide.
- Researchers are already involved in similar interaction research with NAVAIR and MQ-25A.

Seed Research Program 2021

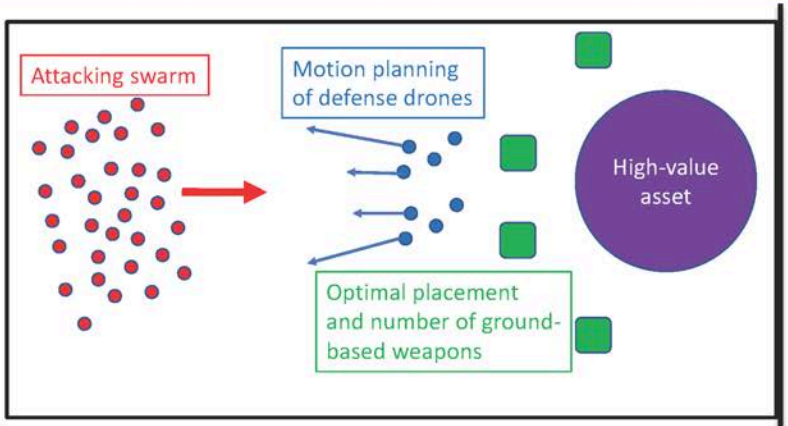
PI: CAPT Scot Miller, USN (ret), Information Sciences Department
Co-PI: Dr Mollie McGuire, Information Sciences Department

Tier II

Autonomy at Large

Autonomy at Large

Developing operational planning simulations for defense against attacking drone swarms



Mission planning for defense against an attacking swarm

Problem Statement

- How should DoD assets be defended again potential large-scale drone attacks?
- What are minimum defense capabilities (numbers and platform specifications) to ensure success?
- Prior work showed proof-of-concept; how to extend to real, operational contexts?

Solution:

- Partner with GBAD / PEOLS / MARCORSYSCOMM to add functionality to address real-world threats

Impact

- Create a tool that could help shape operational planning in large-scale drone and swarm combat.
- Use optimization protocols to build "playbook" of defense strategies against various kinds of autonomous attacks.
- Build relationship between NPS and GBAD/PEOLS/MARCORSYSCOMM

Transition

- MARCORSYSCOMM has endorsed this project (see letter of support); successful project will likely lead to future funding.
- PIs are in active discussions with Triton Systems (a private firm) for a larger proposal on this topic to DARPA / ONR
- PIs submitting proposal on complimentary topic to ONR Science of Autonomy program.

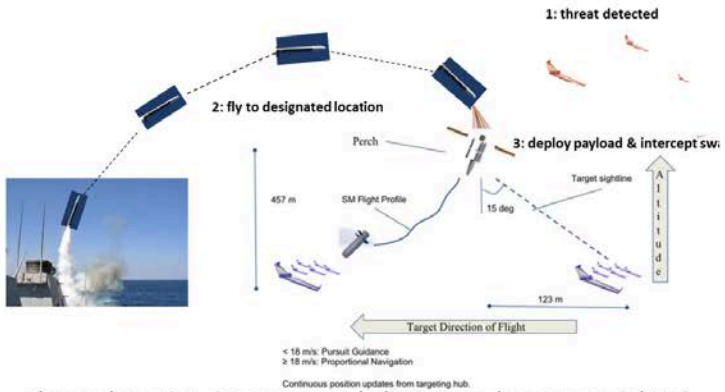
Seed Research Program 2021

PI: Abe Clark, Physics Department
Co-PI: Isaac Kaminer, MAE Department

Tier I

Autonomy at Large

Counter Aerial UxS Munition Delivery System



Threat detection, intercept, and eliminate adversary aerial UxS swarm with multliple guided sub-munitions

Problem Statement

- **Motivation:** The emergence of high-performance, consumer-grade, and low-cost drones, combined with artificial intelligence and low-cost computer processing power, has provided the tools and platforms on which to build UxS drone swarms. In the context of recent weaponization of commercially available aerial UxS, these trends present two major challenges: the possibility of defenses getting overwhelmed and the large cost asymmetry between currently available defenses and the cost of these threats.
- **Approach:** Use cheap COTS and additive manufacturing to build a rapid-response solid rocket motor payload delivery vehicle capable of guiding to a point in space and delivering multiple gravity-fed guided sub-munitions to counter aerial UxS threat(s) with a bird of prey attack approach.

Impact

- **Develop a low-cost guided payload delivery vehicle using commercial off the shelf (COTS) components**
- **Develop required subsystems of target acquisition and tracking sled/perch with onboard logic for directing guided sub-munitions, and gravity-fed guided sub-munition system for threat elimination; all using low-cost COTS components**
- **Provide a more symmetrical response to the threat of cheap aerial UxS swarms**
- **Provide flight data for modeling and simulation of proposed engagements**
- **Training of technical workforce and student development**

Transition

- **DARPA Tactical Technology Office is seeking proportional responses to the ever-growing cheap aerial UxS swarm threat**
- **The U.S. nuclear command, control, and communications systems (NC3) is seeking a rapid-response high altitude delivery system, which can be provided by modifying the payload delivery system being developed.**

Seed Research Program 2021

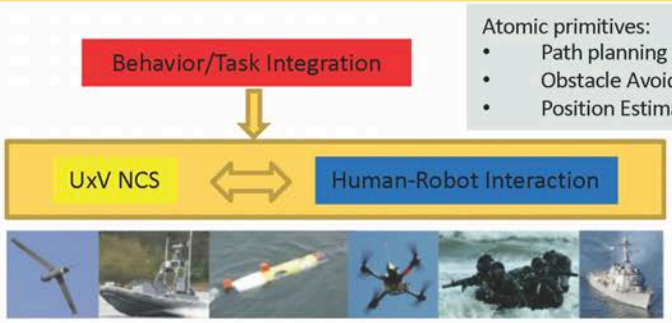
PI: Dr. Christopher M. Brophy, Associate Professor, MAE Department
Co-PI: Dr. Joshua R. Codoni, Research Assistant Professor, MAE Department

Tier I

Autonomy at Large

Behavior Automation for UxV Networked Control Systems

CRUSER Consortium for Robotics and Unmanned Systems Education and Research



- Hierarchy Protocol – manages vertical conflict resolution
- Priority Protocol – manages horizontal conflict resolution
- Behavior Tree manages execution

Components for Behavior Automation of a UxV NCS

Problem Statement

- With a hybrid autonomous/semi-autonomous UxV Networked Control System is it possible for rapid integration of user-defined behaviors?
- How to define abstract behaviors for a UxV NCS?
- How to simultaneously retain system performance while integrating many potential behaviors?

Candidate Solutions:

- AI/ML Behavior Trees and Robust Logistical Dynamic Systems

Impact

- The ability to rapidly integration horizontal and vertical behaviors offers the potential to rapidly increase autonomy in UxV NCS.
- While designed initially for expeditionary forces this applies to a wide set of DoD missions.
- Abstract behavior with UxV NCS specification permits permits independent behavior development.

Transition

- USSOCOM is aggressively looking at integrating UxV NCS into Special Operations missions
- PMS-406 Unmanned Systems has a variety of systems that can be combined to form an UxV NCS to improve a wide selection of maritime mission objectives
- USMC is actively pursuing UxV teaming for expeditionary mission objectives

Seed Research Program 2021

PI: Douglas Horner MAE
Co-PI: Ruriko Yoshida, OR
Co-PI: Geoffrey Xie, CS

Tier I

Autonomy at Large

(FOUO)

Hybrid USV Attacks for Counter-Swarm Experimentation

Hybrid attack by subset of USV swarm with advanced capabilities

Problem Statement

- Capital assets are vulnerable to UxV swarm attacks
- Mass attack by swarm of "dumb" agents can expose defenders to more capable and lethal agents
- Counter-swarm tactics should be tested against complex, hybrid attack strategies
  - Ex: coordination, deception, distraction, lurking, bushwhack, etc.

Solution:

- Incorporate sophisticated autonomy into subset of swarm agents for counter-swarm experimentation

Impact

- Hybrid swarm attacks will "stress test" existing defenses
  - Assess warfighter effectiveness
  - Influence new concepts and tactics
- Augment ONR Counter-Swarm Field Experimentation between Warfare Center S&T and Warfighters
- Active collaboration between NPS & NSWC Carderock

Transition

- Recent meetings with Dr. Michael Qin, ONR Code 34 (Robotics and Autonomy, Hybrid Complex Warfare)
- Dr. Qin encouraged NPS to partner with NSWC at his FY21 "Keep Summer Safe" Counter-UxV Swarm Event
- We will collaborate with NSWC Carderock to integrate NPS autonomy payload onto subset of USV swarm
- High potential for future NPS involvement and reimbursable funding

Seed Research Program 2021

PI: Sean Kragelund, Mechanical and Aerospace Engineering Department
Co-I: Isaac Kaminer, Mechanical and Aerospace Engineering Department

Tier I

Autonomy at Large

Predictive Failure Analysis for Autonomous Networked Ground Stations

MC3 Ground Station used to Prototype ML Algorithms for Predictive Failure Analysis

Problem Statement

- How can MC3 ground stations be autonomously monitored for health and status information to ensure reliability and rapid reconfiguration through predictive failure analysis?
- Can likelihood of future, specific failures be estimated and mitigated before the failure occurs?

Solution:

- The development of specialized software, particularly machine learning and visualization, interfacing with COTS equipment.

Impact

- Transition from reactive to proactive response to ground station equipment failures.
- Demonstrate that machine learning algorithms can analyze the health and status data from ground station equipment and accompanying software.
- Determine hardware and software redundancy required to meet uptime requirements for remote ground stations.

Transition

- DoD Space has fielded a network of sited and remote MC3 ground stations that require monitoring and maintenance.
- Two NPS master's students are working on theses that directly relate to autonomous monitoring.
- The results of this effort to develop predictive failure analysis will be proposed to DoD Space for full scale implementation not only into the DoD Space MC3 ground station network, but into the international FVEYS ground station network.

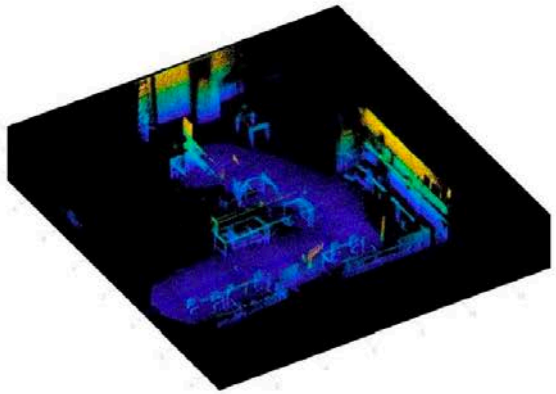
Seed Research Program 2021

PI: Jim Newman, PhD, Chair and Professor, Space Systems
Co-PI: Gio Minelli, PhD, Faculty Assoc Research – Space Systems

Tier I

Autonomy at Large

Localization of Unmanned Ground Systems Using the Zero Velocity Update Technique and a 3-D LiDAR in the Absence of GNSS



3-D LiDAR scan of an indoor lab environment

Problem Statement

- To investigate and exploit the complementary nature of the inertial navigation system (INS) and 3-D light detection and ranging (LiDAR) for localization of unmanned ground systems
- To mitigate the INS error growth resulting from double integration using the zero velocity update (ZUPT) technique
- To combat the IMU orientation error growth using 3-D LiDAR scan matching

Impact

- GPS is widely deployed for accurate tracking of equipment asset as well as personnel. However, GPS signals are susceptible to attack by adversaries via jamming or spoofing
- The proposed approach has the potential to significantly reduce the INS error growth and enable unmanned ground systems to accurately navigate over extended periods of time without GPS

Transition

- The proposed localization method is aimed to meet the Navy's unmanned system (UxS) goals of developing technically superior unmanned systems that are able to navigate accurately in every domain under any environmental conditions
- The feasibility of the approach is to be validated in this proposed effort
- External sources of support for further development are actively pursued

Seed Research Program 2021

PI: Xiaoping Yun, ECE
CoPI: James Calusdian, ECE

Tier I

Autonomy at Large

NPS RoboDojo Maker Lab

- Organizing online learning opportunities. Currently offering an average of 15 learning opportunities per quarter. Workshops topics include: 3D printing, Basic Electronics, Laser cutting/engraving, Software Defined Radios, Intro to Arduino microcontrollers, 3D Modeling, Intro to Raspberry Pi, Linux, LaTeX, LiPo battery safety, user groups, and more.
- Since students, faculty, and staff have limited access to campus, we are remotely supporting rapid prototyping efforts.
- Offering learning kits for student/faculty/staff check-out so that students can learn in their homes and on their own schedules.
- Creating learning videos so that students may learn on their own without attending RoboDojo workshops in person or on a schedule

- The RoboDojo is the NPS community maker lab for learning about robotics electronics, and emerging technologies.
- The RoboDojo offers tools, equipment, instructor-led hands-on workshops, kits of parts, clear documentation, competitions, workspace, open lab hours with enlisted support (in non-COVID times), and user groups around rapid prototyping and emerging technologies.

- To support informal grassroots community interest in learning about robotics, electronics, and emerging technologies
- Exploring robotics, electronics, and emerging technologies can feel daunting to new learners. We strive to remove or to minimize barriers between new learners and the knowledge that they seek. We seek to make learning an enjoyable, well-supported pursuit.
- Lab users have unique perspectives on how to solve wicked problems that the DoD currently faces. We support their explorations in trying to solve these problems.

FY21 Call for Proposals

Tier I

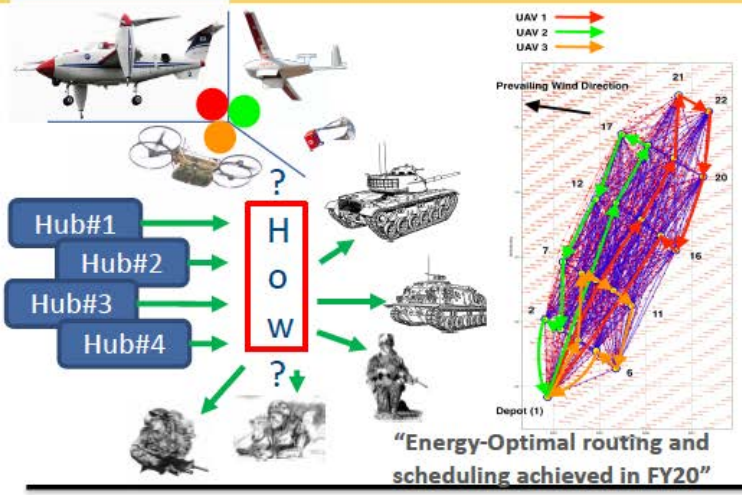
Autonomy at Large

Tier I

Autonomy at Large

Energy-Aware Aerial Logistics in Support of USMC EABO Operation

CRUSER Consortium for Robotics and Unmanned Systems Education and Research



"Energy-Optimal routing and scheduling achieved in FY20"

Problem Statement

- USMC EABO concept needs intelligent logistics that can move supplies from many small depots to widely dispersed forces with minimum energy footprint.
- Challenges of autonomy: limited range & endurance & payload capacity, dependency on weather.
- Challenges of logistics: complex network on the move, many logistics hubs, limited capacity delivery vehicles.

Solution – develop energy-aware routing algorithms to support EABO logistics with autonomous aircraft flying the energy optimal paths.

Impact

- The combined optimization significantly (10-25%) reduces energy consumption by UAVs across the logistics graph.
- Organizing deliveries by priority ensures that "urgent" requests are supported before "routine" requests.
- Autonomy is used to its full extent while combining the capabilities of aircraft and intelligent logistics SW.
- In the real world, energy savings mean longer range, increased carrying capacity, and fuel savings.

Transition

- Multi-Depot Multi-Salesman Vehicle Routing Problem(VRP) to identify optimal placement of resources and UAVs.
- VRP with time windows in order to better support time-specific demands from Marines on the ground.
- Flight energy characterization of hybrid multicopters and tilt-rotor aircraft.
- Integration of VRP solver into the ARL/SURVICE common control module of UAVs.

Seed Research Program 2021

PI: Vlad Dobrokhodov, MAE Department
Co-PI: Kevin Jones, MAE Department
Co-PI: Emily Craparo, OR Department

Tier II

Autonomy at Large

WIEVLE – Development and Testing of a Spherical AUV Platform for Littoral and Confined-Space Operations

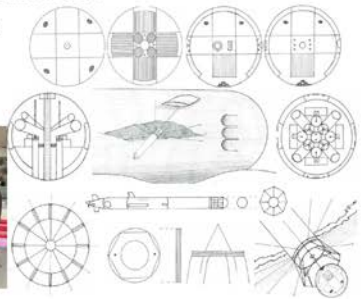
CRUSER
Consortium for Robotics and Unmanned Systems Education and Research

How?

- Advance the development of the UUV toward ***full autonomy***
  - Flight controller programming for autonomous control of the patent pending, quad-core, vectored-thrust propulsion subsystem (shown on right) validated this year
    - Upgraded hover and translation capability
  - Sensor integration within the central payload tube; augmenting embedded camera/LED array (equatorial ring)
    - Surface / sub-surface multi-vehicle network capability
  - Subsystem integration, waterproofing, ballasting and testing in synthetic kelp environments
- Littoral / Confined space test environment development:
  - Test the ability to maneuver / loiter in hostile environments

Impact

- Deliver a multi-mission capable AUV platform
  - Develop payload capability to support networked communications
- Maritime Science or USW journal article submission
- Resident/DL student projects and theses
- Patents, publications and partnerships for the U.S. Navy!



Transition

- The vision: A mission-configurable AUV platform for ***cross-domain*** operations from ***extreme environments*** such as:
  - Contested, entanglement and obstacle-laden near-shore littorals
  - Confined, enclosed underwater compartments
    - ****WIEVLE's architecture was specifically designed for this!****
- MBARI is interested in autonomous tracking of midwater animals
- WIEVLE may provide the warfighter a unique platform for disruptive, emergent weaponization MORAE (**MO**bile **R**obotic **A**mphibious **E**xplosive)
  - Strong N952 Mine Warfare and Mobile Mine Assembly Group interest

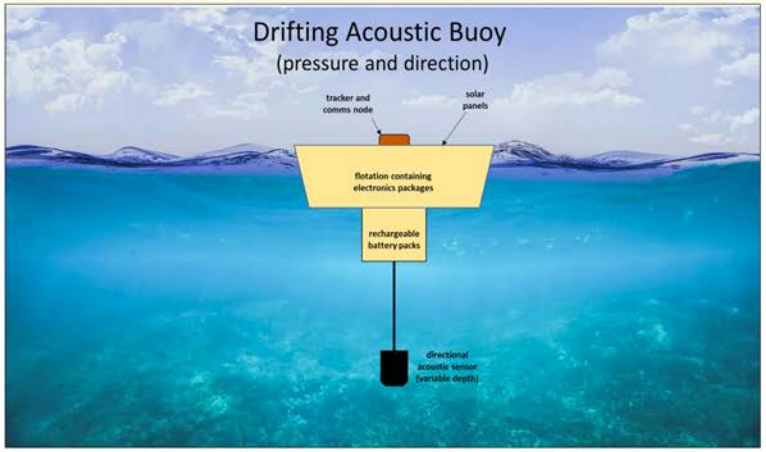
Seed Research Program 2021

PI: Ross Eldred, Faculty Associate - Research, SE Dept.
Co-PI: Dr. Tony Pollman, Assistant Prof., SE Dept.

Tier II

Autonomy at Large

Drifting With Direction



Conceptual design of drifting buoy system

Problem Statement

Develop of a persistent drifting acoustic sensor with these characteristics:

- Measures both acoustic pressure and direction of sound source. Onboard localization algorithms estimate range and direction to target.
- Long-endurance using rechargeable battery pack and solar panels
- Once deployed, operates independently reporting information via Iridium comms
- Continuous acoustic sensing at optimal depths
- Uses detection algorithms to determine when to report.
- Reports tracking information at specified intervals

Impact

- System adds new capability to the undersea domain. System can work independently or use multiple units to get wide-area coverage.
- Long endurance, capable of localizing tracking target with a single unit. Good for queuing threat axis.
- Works independently, overhead assets not required to stay on station to receive data. Data can be sent anywhere
- Multiple systems can be deployed in many configurations depending on the tactical need.

Transition

- Maintaining dominance of the Undersea Domain is a top priority of the USW community. This requires approaches that unmanned systems can bring to the table that were not available just a few years ago
- Current sonobuoy capability is short-lived (hours) and requires overhead assets (P-8) to remain on station to collect data. Once deployed, this system analyzes on-scene data and reports distilled information to command
- New smaller, cheaper and capable technologies and sensors are available now that add improved capabilities not feasible just a few years back

Seed Research Program 2021

PI: John Joseph, Oceanography Department

Tier II

Autonomy at Large

3D-Printed Artificial Muscles Optimization through Experimental Prototyping and COMSOL Simulations, to Enable Quiet Propulsion and Acoustic Translucence of UUVs

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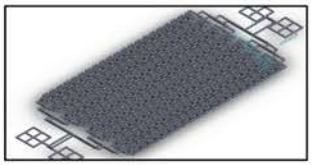
A



B

C

Artificial Muscles. *(A) Shown architecture has 8 parallel muscle fibers. Each fiber is composed of 2 channels entwining in a double helix. Each channel is an array of liquid electrodes, which are alternated with the electrodes of the other channel in the helix, to produce an array of microcapacitors. Applying voltage to the helix would actuate the muscle electrostatically. (B) COMSOL simulations suggest optimal geometries. (C) 3D printed prototype of artificial muscle is composed of 4 fibers positioned in parallel.*

Problem Statement

- We propose to optimize the artificial muscles through a combination of COMSOL simulations, prototyping, and experimental testing.
- COMSOL simulations: Arrays of microcavity electrodes in bulk dielectric will be constructed and biased at a fixed voltage in alternating polarity along the muscle fiber. COMSOL would calculate the output force density in parameter sweeps of geometric dimensions. That will rapidly narrow down the best architectures and scaling to use.
- Prototyping and testing: The prototypes will based on COMSOL-suggested geometries, will be 3D-printed in soft resin,, and will be filled with conducting fluid or gel. Their force output will be measured by force gauges as a function of applied voltage. The experimental results will be analyzed to produce feedback to new designs in the COMSOL simulations. We will iterate the cycle to optimize the devices towards maximized output force density.

Impact

- The survival of naval assets is strongly affected by their ability to evade, confuse, decoy, or trick the enemy. Hence, quiet propulsion and acoustic translucence are highly desirable in friendly UUVs.
- These could be achieved by electrostatically-driven artificial muscles. Our designs for such are based on 3D-printable microfluidic devices made of low-density polymer dielectric and electrically conducting microchannels.
- We are performing COMSOL simulations (see B above) to find the most efficient geometries and sweet spots for the parameters, while we are also prototyping these devices (see C above) for testing and experimental confirmation, all done iteratively to maximize output force.
- We propose to produce an experimental proof of principle for the artificial muscle prototypes by applying voltage and measuring output force by force gauges. Success would be to demonstrate the ability to produce at least 100 lbs of force per square inch in the full-scale version.

Transition

- The result of the work should be of particular interest to the Navy in terms of stealthy UUV propulsion, the Army and Marine Corps for exoskeletal locomotion and powered armor, and the SOCOM community for stealthy UUV transports and improved endurance through force assists.
- In particular, we will seek continued support from SOCOM, IWS, ARO, and ONR.

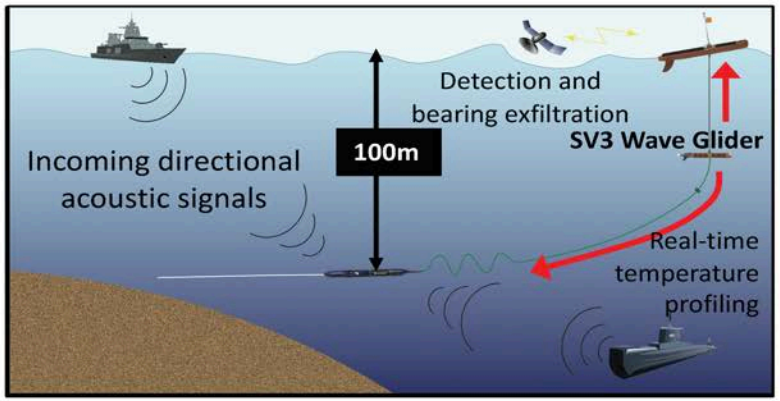
Seed Research Program 2021

PI: Prof. Emil P. Kartalov, Physics Department, GSEAS, NPS,
epkartal@nps.edu, office 831-656-2125, cell 626-260-0300

Tier II

Autonomy at Large

Persistent Mobile Surveillance and Real-Time Target Motion Estimation from a Wave Glider SV3



Wave Glider towing vector sensor, exfiltrating detections and bearings

Problem Statement

- How can undersea sensing be achieved with mobility and persistence?
- How can acoustic detection be automated, and placed where it's required, including remote areas?
- How can the detection information be exfiltrated to inform the warfighter?

Solution:

- Persistent mobile surveillance using a towed acoustic vector sensor from an SV3 wave glider.

Impact

- Ability to monitor undersea traffic in remote locations with broad coverage.
- Achieve unparalleled inference of acoustic and oceanographic environments.
- Prove mobile-agile surveillance CONOP for next-generation fleet awareness
- Expose early-career Naval officers to cutting edge unmanned systems research.

Transition

- PMS485 is interested in next-generation mobile surveillance tools, and towed vector sensor yield many strengths over SHARC concept.
- LMR seeks mobile soundscape solution for mapping large remote areas, e.g. NW Hawaiian Islands
- Extensive collaboration with NUWC enhances research towards fleet applicability.

Seed Research Program 2021

PI: Dr. Paul Leary, Physics Department
Co-PI: Prof. Kevin Smith, Physics Department

Tier II

Autonomy at Large

Autonomous Aerial Damage Assessment

Aerial Damage Assessment with Imagery, LIDAR, Machine Learning

Problem Statement

- How can tight integration between LIDAR and other sensors be achieved in order to provide timely and accurate airfield damage assessment?
- What technology needs to be developed to eliminate the need for remote control of UAS for airfield damage assessment?
- What CONOPS can be developed for fully automated airfield damage assessment for remote, unmanned airfield?
- What types of structural damage assessment can be performed using a similar ADA process?

Impact

Improve Airfield Damage assessment with respect to:

- Speeding up the process of damage assessment
- Increasing accuracy of damage assessment
- Increasing safety of personnel
- A cheaper process

Develop CONOPS for fully-automated ADA for remote, unmanned airfields.

Transition

- NECC is seeking ways to assess damage to structures using Unmanned Systems
- Global ONR NECC is also seeking ways to assess damage to structures using unmanned systems
- ONR Code 32 is seeking ways to determine damage using Imagery and LIDAR with Machine Learning for Airfield Damage Assessment

Seed Research Program 2021

PI: Charles Prince, Computer Science Dept.
Co-PI: Gurminder Singh, Computer Science Chair

Tier II