Drone Net: Applying a Wireless Sensor Network of Fixed and Aerial Instruments for Environmental Monitoring and Security

ICARUS Research Group: ERAU Prescott

Requested Amount: $5,000 - $4200 Student Pay, $800 Equipment

Dr. Sam Siewert (PI): Assistant Professor, Computer and Software Engineering, ERAU Prescott. [CV, Bio].
Dr. Siewert serves as the principle investigator on this research project and he is continuing to help with proposal development as a concluding effort of prior ARI funding. Dr. Siewert's role is project administrator and lead researcher, with specific focus on passive EO/IR and all-sky sensing algorithms and implementation.

Dr. Mehran Andalibi (Collaborator): Assistant Professor, Mechanical Engineering, ERAU Prescott. [CV]
Dr. Andalibi serves as a team member on this research project and he is continuing to help with proposal development as a concluding effort of prior ARI funding. Dr. Andalibi's role is leading the acoustic small UAS detection research and MATLAB simulation and re-simulation of experiments.

Dr. Stephen Bruder (Collaborator): Associate Professor, Electrical Engineering, ERAU Prescott. [CV]
Dr. Bruder serves as a team member on this research project and he is continuing to help with proposal development as a concluding effort of prior ARI funding. Dr. Bruder's role is to define, develop, and implement the necessary data fusion algorithms for navigation.

Mr. Steve Rizor: MS ESE student at CU Boulder, graduation expected in 2020 or later, independently funded and/or working on research for credit, focused on embedded wireless sensor networks that are low power, power-bank (battery) operated, wireless BLE or 802.11, and integrate acoustic, seismic, and optical sensors.

Mr. Jonathan Buchholz (Collaborator): Accelerated MS student, MS UASE program.
Mr. Jonathan Buchholz serves as an MS graduate research student team member working for ICARUS Drone Net with prior funding and for his MS thesis for December 2019. Mr. Buchholz's role is ALTA6 flight systems integration including LIDAR and LWIR instruments and data processing for image handling and fusion for urban UTM experiments.

Ms. Alexandra Lindsey (Undergraduate researcher): BS Software Engineering program student, graduation expected in spring 2020, ERAU Prescott. Assisting Dr. Siewert with self-localizing acoustic sensors, GPS jamming/spoof resilience, and ADS-B.

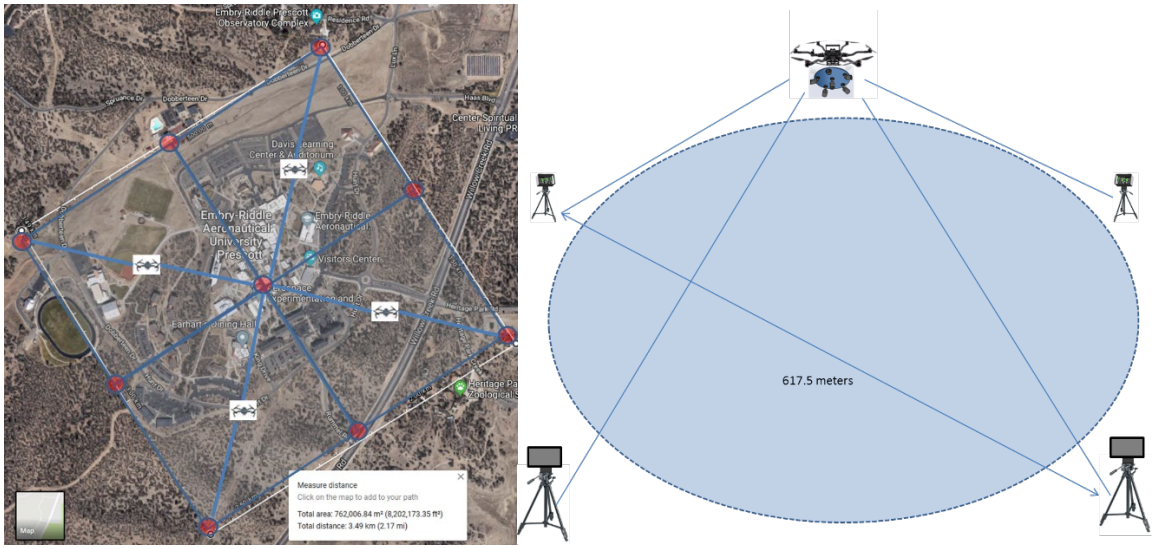
Zachary Johnson (Undergraduate researcher): BS ME Robotics program student, graduation expected in spring 2020, ERAU Prescott. Assisting Dr. Andalibi with acoustic modeling of small UAS, beamforming acoustic sensors, CAD and fabrication of instrumentation mounting and integration for the ICARUS group.

Summary - Large Area Environmental Monitoring

The ERAU ICARUS Research Group proposes to develop further, an open architecture, Drone-Net, to detect, classify, and identify animals (e.g. Rhinos and Elephants), vehicles, and people in sensitive environments. The network-based nature of the proposed technology naturally leads to use for environmental and security monitoring research. For example, anti-poaching wireless sensor networks, environmental monitoring of glaciers, landslide, and volcanic environments. The ICARUS group proposes further research to leverage previously developed Drone Net technology (Video overview) and to add a WSN (Wireless Sensor Network) of devices that can be placed in a mesh or ring around sensitive areas and EO/IR camera systems and/or RADAR/LiDAR. By the end of this proposed research effort, the team expects to deliver a Technology Readiness Level (TRL) four (4) device that would facilitate the pursuit of external funding. The addition of the WSN complements prior work on Drone Net and was tested for feasibility and demonstrated in late 2018 [AIAA SciTech 2019].

As shown in Figure 1, the Drone Net system includes ground sensors on buildings or with tower mounts serving as access points, wider area WSN that can be "dropped in place" as well as sUAS (small UAS) based instruments that can provide on-demand spatial, temporal, spectral remote sensing to compliment the more continuous ground and drop in place sensors. The all-sky 360-degree camera concept used in Drone Net can be used as an aerial instrument to cover and monitor large ground areas from the sky to cue ground-based narrow field EO/IR cameras. This is taking previously developed concepts, and essentially flipping the viewpoint upside down for ground coverage from the sky instead of sky coverage from the ground.

Figure 1. – Drone Net Ground and Aerial Sensing Node Coverage



The top-level goal of this proposed research is to further develop and enhance a real-time drone detection system designed to enhance the safety of the National Air Space (NAS), but adding features for WSN allowing it to serve a mission such as environmental monitoring. Original Drone Net goals that have been realized include the development open architecture, which is sensor and algorithm agnostic. The reference design supports replication at low cost to encourage and facilitate deployment in academic environments. The Drone Net effort has provided students with research opportunities in the areas of heterogeneous information fusion and algorithm development for multi-sensor drone and general target of interest detection, classification, and identification. The principle goal of the currently proposed extension of Drone Net is to explore use of prior research for environmental monitoring and to explore potential to apply to RFP (Request for Proposal)

opportunities to continue past research for specific mission objectives beyond safe use of sUAS in NAS (National Air Space).

Academic Context and Outcomes – Environmental Monitoring of Large Areas

The challenge of effectively monitoring a large area for compliant or expected activity as well as non-compliant and unexpected as a perceptual or situational problem. The problem requires detection, localization of targets of interest (e.g. poachers), classification (e.g. a vehicle) and identification (game warden or unknown). This problem is of general interest as an academic challenge to use passive computer and machine vision (where computer is human like visual intelligence and machine vision cheats to use sensing beyond human capability), acoustic or seismic sensors (to detect animal, vehicle, human presence), combined with active sensing such as LiDAR and RADAR. Likewise, any sort of environmental or security monitoring should combine the capabilities of a human sentry, scientist, or virtual monitor such that surprising events are well recorded, remote security or scientific observers alerted, with vigilant logging of or surprising events. This would be true of glacial or landslide monitoring as well. The WSN provides the data, but one of the significant challenges of WSN and computer and machine vision is how to compress the volumes of data collected at high update rates into highly compressed logs and alerts for human intervention and study.

The fundamental research question of this proposal - how effectively a large ground area can be monitored for expected and unexpected activity? The monitoring effectiveness will be evaluated in terms of:

1) Update rate and detection latency
2) Detection performance in terms of True and False Positives and Negatives (based on staged testing)
3) Spatial coverage and cost to do so (E.g. compared to Digital Globe satellite remote sensing)
4) Spectral coverage (night vision, bad weather, detection of materials such as metals, humans, animals)
5) Temporal coverage (ability to evade detection over time)
6) Situational and perceptual awareness improvement (compared to field science or security patrols)

Specific outcomes of the proposal to add WSN to Drone Net and to test ability to detect ground as well as aerial events, extends the value of the machine vision and machine learning applications development as well as localization of sensors (automatic) and the ability to determine if sensors have been moved, tampered with, or hacked in some fashion. Students working on Drone Net will have more sensor data (current all-sky, EO/IR-Rev-A, tracking, urban data) to evaluate salient object detectors, R-CNN (Region of Interest Convolutional Neural Networks), acoustic and optical passive sensor fusion, as well as combined sensing with active instruments (LiDAR and RADAR). Showing that ground an aerial objects can be equally well detected, localized, classified and identified, will vastly increase the value of Drone Net beyond safe urban sUAS (small Unmanned Aerial Systems) navigation, to also include environmental monitoring.

Beyond the research proposed, the capabilities, instruments, methods and theory developed can be used in classes including:

1) SE 310 – Object Oriented Software Systems Design
2) SE 420 – Software Quality Assurance
3) CS 317 – Database and File Systems
4) CEC 450 – Real-Time Systems (potential)
5) New class on machine vision
6) New class on machine learning
7) New class on instrumentation, WSN (Wireless Sensor Networks) and IoT (Internet of Things)

Material, examples, the problem definitions for Drone Net have already been used in the above classes as design, test, and analysis examples. In several cases, students interested in Drone Net have already taken on design class semester long projects to work on an aspect of the Drone Net research.

Student Involvement

A primary goal for this project is to support summer experimentation using Drone Net existing elements (RADAR, EO/IR, acoustic nodes, aerial LiDAR and EO/IR) to collect new ground monitoring data and to improve the WSN. Students at ERAU will be employed to work on Raspberry Pi 3b+ acoustic sensors that are self localizing with GNSS/GPS (Global Navigation Satellite System / Global Positioning System) and INS (Inertial Navigation System) sensors integrated with the Raspberry Pi, that will in turn alert ground monitoring cameras (EO/IR roof mount) or aerial 360 degree. The goal is to involve the students in the improvement and use of instruments (e.g. ruggedizing for outdoor use), their applications for specific missions (e.g. anti-poaching patrol) and to understand the limits of each (spectral, spatial, temporal) and how they can be used to detect, localize, classify and identify objects in a scene.

Furthermore, the assumption of this project is that WSN sensors might be tampered with, so students will work on methods to detect tampering (moving a sensor) and to provide resilient operation (continuous monitoring) despite potential physical or virtual attack on the system.

Faculty Development

The ICARUS faculty have a common interest in multi-modal, active/passive, sensor networks and the processing of this data for detection, localization, and classification and identification problems. The ICARUS faculty group has developed Drone Net and the goal here is to explore situational monitoring problem spaces in more both breadth and depth. A specific goal is to explore the fail-safe and fail-secure WSN features that are resilient when attacked through the network or with direct physical tampering. The ICARUS team has started collaboration with other campus colleges including Aviation Science and Cybersecurity. Continued student involvement and faculty interest will help further develop capabilities to respond to new opportunity with industry, government agencies, and within ERAU.

External Funding Opportunity

The ICARUS group plans to submit an external funded proposal in summer/fall 2019 and again in summer/fall 2020 if necessary. The current list of potential sources of funding and their status are summarized in the table below:

Source	**Status**	**AO/RFP**	**Type**
EPI-USE	Explore	Discussion with URI	Environmental
AFRL	Explore	Wright Brother's Institute Workshop	Military
ONR	Explore	Discussion with Research Program Officer at AIAA	Military
KBRWyle	Explore	AFRL Workshop discussion and interest	STTR

Xwing Company	Explore	Phone contact with CTO	STTR
NSF	Accept anytime	CCSS - https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505248	Agency
NSF	Due 6/6/19	RTML - https://www.nsf.gov/pubs/2019/nsf19566/nsf19566.htm?WT.mc_id=USNSF_25&WT.mc_ev=click	Agency
NASA UTM/UAM	Need to identify	• https://nspires.nasaprs.com/external/ • https://www.nasa.gov/aeroresearch/programs/iasp/uas	Agency
Daytona Collaboration	Explore with Dr. Song	• NASA University Leadership Initiative (ULI) • DARPA-SN-17-77: Detection and Negation Ideas for Protecting Against Small Unmanned Air Systems • U.S. Air Force RFI-RIKD-19-01: Counter-small Unmanned Air Systems (C-sUAS) • FAA RFI Data Exchange Strategies and Demonstrations for UAS Remote Identification • NSF 16-123 Dear Colleague Letter: Supporting Fundamental Research in Unmanned Aerial Systems (UAS) • U.S. Air Force and NSF Mutual Letter of Intent between the Department of the Air Force and the National Science Foundation Concerning a Partnership to Coordinate Mutual Research Interests	MAU

Summer Schedule – Focus on Acoustic, RADAR and GPS/ADS-B Security

Term	**Summer A**						**Summer B**					
Week	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**
Alex L. Acoustic Sensor	Design walk-through	Coding	Testing	Design Revision	Coding	Testing	Plan Monitoring test	**Test A**	Analysis	**Test B**	Analysis	Document
Zachary J. Acoustic	Design walk-through	Coding	Testing	Design Revision	Coding	Testing	Plan Monitoring test	**Test A**	Analysis	**Test B**	Analysis	Document
Steve R. Acoustic	IS research	IS research	IS research	IS research	IS research	IS research	IS research	**Test A**	Analysis	**Test B**	IS research	IS research
Sam S.	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	**Test A**	Analysis	**Test B**	Advising, Proposal	Advising, Proposal
Mehran A.	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	**Test A**	Analysis	**Test B**	Advising, Proposal	Advising, Proposal

Stephen B.	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	Advising, Proposal	**Test A**	Analysis	**Test B**	Advising, Proposal	Advising, Proposal

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