Research Agreement

This Research Agreement ("Agreement") is made and entered into effective as of the ____ day of September2018 by Eversource Energy Service Company, as agent for The Connecticut Light & Power Company, having principal offices at 107 Selden Street, Berlin, CT 06037 ("Company") and UNIVERSITY OF CONNECTICUT ("University") to provide research and related services described in the exhibits hereto pursuant to the terms of the SECOND AMENDED AND RESTATED SPONSOR RESEARCH AND SERVICES AGREEMENT between Company and University dated May 1st, 2015 (the "Sponsor Research Agreement") with the exception that wherever "Company" is referenced in the Sponsor Research Agreement, "Company shall be deemed to be the applicable affiliate of Eversource Energy Service Company listed below for which the University is performing services.

Payment by Company in the amount of Two hundred eleven thousand, one hundred and eighty dollars ($211.180.00) will be made to University within thirty (30) days of full execution of this Agreement. Funding for the work to be performed under this Research Agreement and attached Statement of Work shall be provided by the Company. For the purposes of clarification, the funding provided herein is in addition to the funding already provided in the Sponsor Research Agreement and is not subject to Section 2, Exhibit A or Schedule A.

Both Parties agree to participate in Research to be conducted in accordance with the terms and conditions of the Sponsor Research Agreement (including the exception for the definition of "Company" as noted above) and this Agreement, provided however, that in the event of a conflict between the terms and conditions of the Sponsor Research Agreement and this Agreement, the terms of the Sponsor Research Agreement shall be controlling.

1. **Title of Research Project: Physical Security: Detection of UAVs (Phase II)**
2. **Research Project Description:**
    a. **Problem Statement**
    b. **Proposal Objectives**
    c. **Methodology**
    d. **Data Requirements**
    e. **Project Deliverables**
    f. **Project Timetable and Milestones**
3. **Project Dates: 1/1/19 – 12/31/19**

University of Connecticut

By PI: Jason Parent

Printed Name: Jason Parent

Title: Professor

Date: 8/27/18

Eversource Energy Service Company, as agent for The Connecticut Light and Power Company

By: [signature]

Printed Name: Sam Woodard

Title: Director

Date: 9-14-18

By Sponsored Program Services: [signature]

Printed Name: Laura Kozma, Executive Director

Date: 9/14/18

Research/Project Description: Protecting Critical Infrastructure from UAV Threats – Developing New Options for UAV Detection

Jason R. Parent (lead), Chandi Witharana, Emmanouil N. Anagnostou, Tom Meyer

A. *Problem Statement*

The proliferation of unmanned aerial vehicles (UAV) poses a potential threat to critical infrastructure from both terrorist and non-terrorist activity. Terrorist activities could include reconnaissance of future targets as well as delivery of explosives or other hazardous payloads to target infrastructure. Damages could also be caused unintentionally from UAVs colliding with power lines or substation equipment. The small size and low flying height of most commercial UAVs makes them difficult detect or identify using conventional detection systems. Commercial detection devices that are currently on the market can be prohibitively expensive to deploy with costs for devices ranging from $200 – 800K. In addition, previous reviews of these devices have found that they have not been rigorously tested and demonstrated to be effective against a variety of UAV threats. The proposed research would explore the development of alternatives to existing commercial devices that could potentially be deployed at a lower cost. This research would be "proof-of-concept" and aim to adapt existing remote sensing technologies to the purpose of UAV detection. These technologies would include RADAR, LiDAR, and optical devices. Detection of UAVs will almost certainly be a necessary precursor to UAV neutralization when such options become available in the future.

B. Proposal Objectives

This project would explore the development of UAV detection devices by adapting existing remote sensing technology including RADAR, LiDAR, and optical devices. This work would be proof-of-concept and help identify technologies that warrant further investigation and development as UAV detectors. The specific project objectives are to:

- Evaluate the effectiveness of RADAR in detecting UAVs,
- Evaluate the effectiveness of LiDAR in detecting UAVs,
- Evaluate the effectiveness of optical and thermal cameras in detecting UAVs,
- Perform cost-benefit analysis for investments in securing substations against UAV threats.

All devices will be tested under varied environmental conditions (i.e. blue sky, clouds, etc.) and settings (i.e. urban, rural) in order to determine their strengths and weaknesses for UAV detection.

C. *Methodology & Project Tasks*

The scope of work will be accomplished by performing the following tasks:

Task 1: Evaluation of RADAR: RADAR has traditionally been used to detect and track airborne objects; however, traditional radar systems are not designed to detect low, slow, and small moving aircraft such as commercial-grade UAVs. Based on our preliminary investigations, the radar systems that have been tuned and marketed for UAV detection cost more than $500K. This task would explore lower-cost alternatives to the current radar-based devices on the market including a moderate-cost ($30K) phased radar and a low-cost marine radar ($3K). We will explore the capabilities of the experimental phased radar array as well as conduct proof-of-concept testing on the marine radar to determine its potential for further development as a UAV detector. RADAR is expected to be suitable for UAV detection during all environmental conditions (e.g. day, night, etc.).

Task 2: Evaluation of LiDAR: LiDAR has been used in remote sensing to map the features on earth's surface as well as the insides of buildings. The laser pulses are capable of detecting small features in the environment and even low-resolution LiDAR data collections frequently detect large birds (e.g. Canada geese). We expect ground-based LiDAR to be able to detect small airborne objects within a range of 30-

100 meters. The cost of conventional LiDAR scanners has dropped rapidly in recent years to as low as $8K for small, short-range devices and costs are predicted to continue dropping. This task would perform proof-of-concept testing for LiDAR-based detection devices focusing on low-powered systems that are safe for use in ground-based systems. LiDAR is expected to be suitable for UAV detection for both day and night during fair weather conditions.

Task 3: Evaluation of Optical and Thermal Sensors: Optical and thermal security cameras are already standard equipment for addressing ground-based threats and they may also be applicable to detecting UAV threats. Cameras are available with wide-angle lenses and optical systems can cover a full 360 field-of-view and allow for continuous full-sky scanning. Optical cameras would be suited to daytime surveillance while thermal cameras would be suited to nighttime surveillance. Both optical and thermal systems would provide low cost options for UAV detection. This task would perform proof-of-concept testing for both optical and thermal camera systems.

Task 4: Economic cost-benefit analysis of investing in UAV security: Investments in UAV security should balance the cost of investment with the probability and cost of an attack on the utility grid. This task will conduct a cost-benefit analysis assessing the benefit of UAV protection with the cost of currently available detection and neutralization options. This analysis will help inform security investment decisions as well as justify the associated expenditures.

D. Equipment Requirements

Tasks 1, 2, and 3 is contingent on Eversource providing additional funding to support a UAV test facility. The test facility would include detection devices (i.e. a phased array radar, a marine radar, a LiDAR system, and optical and thermal cameras) as well as a variety of UAVs (i.e. fixed-wing, a mini-class light copter, a mini-class heavy copter, and a nano-class copter) with which to test the detectors.

E. Project Deliverables and Timeline

Date (2019)	Activity Reports	Deliverables	Related Tasks
June	- Development of UAV test facility - Preliminar testing of devices	- Report on progress	1, 2, 3
December	- Proof-of-concept evaluations of marine RADAR, LiDAR, optical, and thermal devices. - Evaluation of phased array radar. - Cost-benefit analysis	- Reports on progress	1, 2, 3, 4

F. Budget

Budget total: The total budget amount requested, for this project, for a period spanning from Jan. 1, 2019 to Dec. 31, 2019 is **$211,180**. The budget includes full academic year support for one graduate student, partial academic year support for two assistant professors (Parent, Witharana), and partial summer salary for two professors (Anagnastou, Meyer) and one assistant professor (Borochin).

Activity Reports	Deliverables	Related Tasks	Estimated budget
- Creation of UAV test facility – i.e. personnel training, establish test locations, etc. - Data collection with RADAR, LiDAR, optical, and thermal sensors. - Data analysis and preliminary algorithm development	- Report status of test facility. - Report on outcome of sensor tests and algorithm development.	1, 2,3	$185,291
- Cost-benefit analysis	- Report on cost-benefit analysis	4	$25,889