MIT Lincoln Laboratory
UROP Projects at Lincoln Laboratory

Fall 2018 – Spring 2019

Faculty Coordinator: Professor Jeffrey Shapiro

12 September 2018
“Multi-Spectral Ground Analysis using Overhead Imagery and Machine Learning”

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Joseph Muñoz and Sami Amasha (Group 31)

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Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Synthetic Aperture Radar, Classification Algorithms

The advent of on-demand optical imagery from space has provided a wealth of data about the Earth’s surface and changed the way we think about issues from privacy to navigation. An under-utilized avenue for exploiting these data sets and magnifying their benefits is to fuse them with measurements from other wavebands such as maps made using synthetic aperture radar (SAR) from airborne platforms. Because objects look different when exposed to different wavelengths, this multi-spectral approach has the potential to expand our ability to characterize and classify the images formed from the data, especially using machine learning techniques.

Our group has access to large SAR datasets ripe for exploitation in this way and are looking for a highly-motivated student to help our team combine this data with publicly available Google Maps or GIS data as well as other complementary information sources such as Department of Agriculture soil surveys. The student will investigate classification or machine learning schemes to identify terrain and soil characteristics based on optical data. They will then correlate these results with SAR maps to add radar backscatter information while learning about SAR techniques and gaining experience calibrating and processing raw radar data.

Prerequisites:

- Strong motivation to learn a variety of new concepts and techniques in physics, algorithm development, and data processing

- Some programming experience and willingness to work in Matlab

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Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Elizabeth Godoy, Zachary Chance (Group 36)

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Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Signal Processing, Machine Learning

Rapid technology advances, such as in software defined radio, are resulting in increasingly congested and dynamic spectrum channels. A key for radio frequency (RF) systems to operate efficiently in such conditions is the ability to sense, i.e. detect and characterize, the RF transmission environment. Sensing diverse, unknown or changing waveform patterns is especially challenging for many modern RF systems. To address this problem, the candidate will design and evaluate new sensing algorithms that combine traditional signal processing with emergent pattern recognition (i.e. machine learning) techniques. This project offers opportunities to learn and apply a wide range of tools, from classical detection theory to current deep learning with neural networks.

The candidate should be pursuing an undergraduate degree at MIT with interests in electrical engineering, computer science, physics or applied mathematics. Proficiency with Matlab, Python or a similar programming language is preferred.

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“Autonomy Validation for Undersea Mission Planning”

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Joe Edwards (Group 37)

Contact: joe.edwards@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Signal Processing, Computer Science (Numerical Methods)

The goal of this project is to develop an autonomy validation engine to ensure planned undersea missions will be successfully completed in uncertain environments.

As unmanned undersea vehicle (UUV) technology develops, UUVs are being tasked with longer and more complex missions. To successfully accomplish these missions, the vehicle must be able to autonomously transit to its work site, maneuver appropriately for its assigned tasks, and return safely, while contending with potential contingencies including uncooperative ship traffic, unexpected current flows, or sensor/actuator failures. Due to the high cost of mission failures, mission planners need an ability to assess the risk to the mission posed by unforeseen contingencies prior to launch. The large
The number of uncontrolled variables creates an exploding space of mission outcomes, so methods to find the most important simulation scenarios, or to develop performance bounds, are preferred over brute force simulation of all possibilities to determine risk. In this project, the student will develop tools to assess the pre-mission risk to UUV missions involving oceanographic effects and interfering ship traffic, to be validated using a real-time mission simulator.

The candidate should be pursuing an undergraduate degree at MIT and have proficiency with Matlab, C/C++, Python, or other similar programming language.

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**“Object Classification in Infrared Imagery”**

**Faculty Coordinator:** Professor Jeffrey Shapiro (jhs@mit.edu)

**Lincoln Mentor(s):** Lily Lee (Group 46), Joel Grimm (Beaver Works)

**Contact:** Grimm@ll.mit.edu

**Location:** MIT Lincoln Laboratory (U.S. citizenship required)

**Research Area:** Autonomous System

The goal of this project is to develop neural networks trained on infrared camera imagery for classification of people, animals, and objects in non-lit conditions.

There are many papers and active research areas on using neural networks and machine learning to identify and classify objects using inexpensive visible image sensors. Infrared cameras are still called imagers, but they detect photons from a completely different spectral band and neural networks trained with visible imagers do not take advantage of features prominent in IR. In this project, the student will test neural networks trained on visible imagery on IR imagery, investigate the different features apparent in IR imagery, build databases and train neural networks to correctly classify objects in static scenes and video.

The candidate should be pursuing an undergraduate degree at MIT and have proficiency with GPU processing, (e.g. TensorFlow), MatLab, Python, or other similar programming language. Demonstrated analysis skills are a plus.

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"RF Propagation Modeling for Confined Spaces"

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Joe Belarge (Group 46), Joel Grimm (Beaver Works)

Contact: Grimm@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Modeling and Simulation

The goal of this project is to develop an accurate model for the propagation of RF energy in confined spaces such as tunnels, that can provide better basis for estimating communication links and possibly provide new approaches to mapping/sounding out confined spaces post-disaster.

Free-space propagation of RF energy is well understood and modeling programs (like Ansys High Frequency Structure Simulator: HFSS) exist, modeling and simulation of RF energy in tunnels or other similar confined spaces is not yet done at high fidelity. HFSS does not deal with boundary conditions and multiple modes in a way that allows for accurate propagation of RF energy beyond a few modes or that provides a way to input actual confined space 3D maps for integration into the model. The student will build the tools to model the propagation of RF energy in confined spaces beyond current capabilities.

The candidate should be pursuing an undergraduate degree at MIT and have deep understanding of EM fields and propagation, proficiency with HFSS and MatLab. Demonstrated analysis skills are a plus.

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"Teaching Machine Learning Systems to Learn"

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Swaroop Vattam, Pooya Khorrami (Group 52)

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Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Data Science

Help dramatically expand the applications of machine learning by automating the process of constructing machine learning solutions. It currently takes machine learning experts weeks or months to solve new problems. Automating this process will decrease the time required by these experts to create solutions and may make it possible for biologists, physicians, urban planners, and others without a machine learning background to interact with an automated system and obtain high-quality solutions.

Training such an automated system requires many datasets with machine learning solutions to a wide variety of problems. We are looking for students to help gather unprocessed datasets from the
internet that include raw data and a problem of interest. They must curate the data and construct solutions to develop a community-wide resource that can be used to train automated machine learning systems. Each student will be challenged with a wide range of problem types and machine learning applications that require solutions. Students will also develop an automated learning system using the datasets as they are generated. To facilitate large-scale data processing and model learning, students will have access to the computing resources of the Lincoln Laboratory Supercomputing Center.

This project is an opportunity to be supervised by leaders in the field from MIT Lincoln Laboratory in the Human Language Technology and other groups. The candidate should be pursuing an undergraduate degree at MIT and must have demonstrated experience implementing machine-learning systems.

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“When an Unmanned System is Hacked, How Do We Survive?”

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Michael Vai, David Whelihan, Ben Nahill (Group 53)

Contact: mvai@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Security for Unmanned Systems

Delivery drones, robots, self-driving cars, and small satellites, what do they have in common? They are very cool! Yes... But imagine this! You have ordered a much needed printer cartridge so that you can finish your report due at midnight. Sadly, the promised 15-minute delivery never materialized. The delivery drone heading towards your residence was hacked and delivered your package elsewhere. This may not be that bad, but what if an adversary were able to commandeer our self-driving cars or satellites en masse? These cyber-physical systems are typically built with little concern for cyber security.

As a UROP in our group, you will help us change that by creating highly-usable and easy-to-integrate security solutions for such systems. You will be mentored by experts at Lincoln Laboratory and will get hands-on experience analyzing, innovating, and prototyping practical security approaches, as well as creating compelling demonstrations to showcase their work. Follow-on summer internships and MEng research assistantships / thesis projects after your SB are a possibility too.

We are looking for high energy self-motivated MIT Course VI students who have experience and interests in software, hardware, and embedded systems development and are interested in growing these skills and acquiring new ones by applying them to improving security and usability of future cyber-physical systems.
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“Development of Self-Phase Modulation Analysis Code”

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Ronald Parenti (Group 66)

Contact: parenti@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research area: Laser Communications

Self-phase modulation (SPM) is a non-linear interaction in optical fibers that occurs at high intensity levels, and is particularly troublesome when phase modulation is used for data encoding. To understand the impact of this effect on a communications link, it is useful to accurately quantify the relationship between signal power and the magnitude of the phase shift observed by a coherent receiver. A MATLAB® program designed to perform an off-line analysis of this effect is currently in an early stage of development; however, this code lacks a user-friendly I/O interface and the documentation needed to enable experimentalists to utilize this software in a real-time laboratory environment. If time permits, the work can be extended to multi-wavelength communications waveforms, where both self- and cross-phase modulation, as well as four-wave mixing (all manifestations of the same nonlinear process) can impact performance.

The goal of this project is the development of a robust software module that could be transferred to laboratory hardware in order to provide a near real-time assessment and visualization of the observed signal degradation due to self-phase modulation. The candidate for this position should be pursuing an undergraduate degree in physics or engineering at MIT, and have proficiency in both MATLAB and Simulink®. Students with a basic understanding of communication theory and some experience with fiber optics would be given preference.

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“Software Engineering Boot Camp, Applied to Laser Communications Systems”

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Jonah Tower (Group 66)

Contact: jonah@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Software Engineering with Applications to Laser Communications Systems

The student will be presented with a software engineering project that the student will “own” – being responsible for design, development, and implementation. With the guidance of experienced
engineers, the student will participate in a "software engineering boot camp.” The student will be asked to develop requirements, produce a project design, implement the software per the student’s own design and using technologies of the student’s choice, and integrate and test the solution. Student projects are intended to be of a quality and importance such they can be delivered as part of major systems.

The candidate for this position should be pursuing an undergraduate degree in computer science, any engineering discipline, or physics at MIT, and have experience in software development. The student need not be experienced in the systematic methodology of software engineering, as the boot camp is designed to help the student learn these skills hands-on, and to gain the broader perspective of a complete software engineering project life cycle.

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“Testing High Performance Thermal Components For Space Applications”

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Allie Norloff (Group 74)

Contact: Allison.Norloff@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Heat transfer

High performance payloads with high powered electronic assemblies in small packages present thermal design challenges in meeting both performance and survival requirements. These challenges are compounded when designing for space environments. Traditionally, these requirements have been met by using materials such as copper and aluminum that have been made into thermal links, card locks, and radiator thermal doublers. However, these materials are heavy and may not be able to support the heat transfer requirements of future programs.

Small companies that manufacture thermal management products are constantly innovating to deliver new products that promise enhanced thermal performance at lighter-weights. This project will investigate these novel solutions. Expanding the thermal solution design space by including these novel solutions increases the range of thermal management options that potentially result in superior performance and reliability, and reduced risk.

Thermal components will be purchased for in-house testing and evaluation. The results will compare the thermal performance of novel thermal components to heritage thermal components. Characterization of the various components will help determine which products are best suited for future applications.

The ideal student for this project will have a basic understanding of heat transfer and an interest in conducting experiments. The student should be pursuing an undergraduate degree at MIT.

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"Multifunctional Structures"

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Michael A. Echter (Group 74)

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Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Multifunctional Structures with Low-SWaP, Integrated Actuation and Sensing

Multifunctional Structures (MFS) are enabled by the hybridization of discrete materials and technologies to perform tailorable functions for an application. These structures have the ability to change and adapt to their environment on-demand, increase performance, or even serve multiple separate functions. Several applications of this include (but are not limited to): active structures for vibration and noise suppression, structural shape adaptation, thermal compensation, morphing wings for UAVs for adaptive flight profiles, structural health monitoring, energy harvesting structures, and reconfigurable structures.

Currently multi-mission objectives are achieved by separate systems, such as an optical assembly with a single degree of freedom focus compensation stage to move a single optic. A multifunctional structures approach removes this discretization and often further advances capabilities while lowering SWaP. That same optical assembly might be designed to have the structure capable of adapting to the environment using feedback from integrated sensors to control integrated actuators to morph the mount geometry and maintain alignment over multiple degrees of freedom.

This project will address the sensor side of a feedback control system required to enable low-SWaP structures that can self-assess performance and health, and consequently be capable of correcting itself using integrated piezoelectric Macro Fiber Composite (MFC) actuators. An interesting benefit to using piezoelectric actuators is that they can also be used as sensors, with the caveat that only higher frequency dynamic responses can be measured due to charge dissipation over short timescales. To minimize the complexity of a multifunctional structure with integrated actuation and sensing it is advantageous to utilize these piezoelectric actuators as sensors for feedback to the control system; however, low frequency response characteristics are also needed for static positioning and long timescale error corrections (e.g., thermal gradients) and therefore additional sensors are required.

While a large number of sensors (on the order of the number of actuators) capable of measuring low and high frequency responses could be applied to this type of multifunctional structure, the cost and additional support hardware can quickly become prohibitive of a low-SWaP objective. Instead, a sensor fusion technique will be used where a small number of sensors capable of measuring low frequency response will be strategically placed on the structure and used in-concert with a subset of the piezoelectric actuators/sensors to gain wide-bandwidth frequency insight into the performance of the structure.

The candidate should be pursuing an undergraduate degree at MIT and have proficiency with MATLAB Simulink, preferably using a Speedgoat real-time target machine. A background in actuator and sensor selection, signal processing, strain gauges, precision instrumentation, and/or sensor fusion techniques is highly desired.

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"Structural Materials Development for Aero, Astro and Optical Systems"

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Todd M. Mower (Group 74)

Contact: mower@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Materials Science and Engineering

Several efforts are currently underway in the Structural and Thermal-Fluids Group focused upon introducing new structural materials into the design and fabrication of state-of-the-art sensor systems that are frequently challenged by constraints of size and weight. The thrusts of this effort are two-fold. On one path, we are seeking to adopt recently commercialized materials that offer promising mechanical and/or thermal properties, but have not yet been utilized in Laboratory prototype systems; to obtain confidence necessary to use these materials in programs with low tolerance for risk, we perform many types of mechanical and thermal characterizations on samples of new materials, to provide design engineers with confirmed property data. On another, bolder path, we are seeking to develop new metal materials for powder-bed laser-fusion additive manufacturing (selective laser melting, SLM). In this effort, we are currently focusing on producing a ceramic-reinforced aluminum alloy that offers significantly higher specific stiffness than is displayed by any other material presently available for additive manufacturing.

New structural materials that could potentially benefit Laboratory prototype assemblies include advanced carbon-fiber composites, metal matrix composites (MMCs) such as aluminum matrices reinforced with either alumina or silicon carbide particles, and novel MnCu alloys with intrinsic damping behavior. Aspects of these materials that could be explored by the interested student researcher could be: performing fracture toughness measurements of novel MMCs, measuring the fatigue strength of MMCs and correlating that behavior with microstructural features, measuring many properties (strength, stiffness, thermal conductivity and expansion, as well as damping behavior) of metals with high intrinsic damping, and relating those characteristics to the microstructures.

Our path towards producing a metal matrix composite for selective laser melting depends heavily upon preparation of an appropriate precursor powder, with a favorable balance of composition, particle size distribution and flow characteristics (spreadability). Our efforts are currently concentrated on using a high-energy ball mill to prepare powders with the “mechanical alloying” process, which involves selection of several independent variables (ball size, ball-to-powder weight ratio, speed and choice of surfactant, or process control agent). One topic that a student could explore is the effect of many combinations of process variables upon characteristics (particle size, flowability) of the milled powder. As we begin to consolidate our powder in our research-focused SLM system, we will characterize mechanical properties of solid samples using a state-of-the-art microindentation system. A student with strong theoretical interests and aptitude could focus their efforts on devising a protocol for performing indentation testing on our samples, and developing analytical techniques to analyze the indentation data in a manner that can produce accurate estimates of the material’s yield strength.

The candidate should be pursuing an undergraduate degree at MIT, have some formal education in mechanical behavior of materials, an interest in novel structural materials, and a proven eagerness to learn how to use new instrumentation.

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"Infrared Polarization, Astrophysical Dust, and Star-formation"

Faculty Coordinator: Professor Jeffrey Shapiro (jhs@mit.edu)

Lincoln Mentor(s): Sumanth Kaushik (Group 91)

Contact: skaushik@ll.mit.edu

Location: MIT Lincoln Laboratory (U.S. citizenship required)

Research Area: Astrophysics, Infrared Polarization

Polarized light is one of the few ways of remotely measuring magnetic fields and has implications for many fields of astrophysics including studies of the solar wind, star-formation, and the cosmic microwave background. It is not well-understood how the polarized light traces magnetic fields, or in what types of physical environments the correspondence fails. The current project will use new far-infrared data to study the dust-induced polarization in regions of active star-formation and compare it to other data sets tracing temperature, density, and interstellar chemistry.

Data sets that might be examined include (but are not limited to) polarization of starlight and emission from Galactic clouds, photometric imaging, and spectroscopic observations from several space- and ground-based observatories. Duties may include identifying relevant data sets, calibration of raw data, assisting in generation of computer models.

Prerequisites:

- Programming experience in C/python/matlab/IDL or equivalent
- Strong interest in Physics and/or Astronomy
- Physics I and II (8.01x and 8.02x), or equivalent
- Student in 2nd-year undergrad or beyond, preferred

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