2020 REU Projects

Project 1: Deep Learning to Improve Ultrasound and Photoacoustic Image Quality
Mentor: Professor Muyinatu Bell

Project Description:
Deep learning methods are capable of performing sophisticated tasks when applied to a myriad of artificial intelligent research fields. This project builds on our pioneering expertise to explore novel approaches that replace the inherently flawed beamforming step during ultrasound and photoacoustic image formation by applying deep learning directly to raw channel data. In ultrasound and photoacoustic imaging, the beamforming process is typically the first line of software defense against poor quality images.

Role of REU Student:
Implement simulations of acoustic wave propagation to create a sufficient training data set; train and test multiple network architectures; data analysis and interpretation

Preferred Background & Skills:
Programming experience in MATLAB and C/C++; experience with Keras and/or TensorFlow; familiarity with computer vision and basic deep learning techniques; experience with ultrasound imaging and would be helpful, but not required.

Project 2: Photoacoustic-Guided Surgery

Mentor: Professor Muyinatu Bell

Project Description:
Photoacoustic imaging is an emerging technique that uses pulsed lasers to excite selected tissue and create an acoustic wave that is detected by ultrasound technology. This project explores the use of photoacoustic imaging to detect blood vessels behind tissues during minimally invasive surgeries, such as neurosurgery, spinal fusion surgery, and gynecological surgeries like hysterectomy.

Role of REU Student:
Literature searches; phantom design and construction; perform experiments with *ex vivo* tissue; data analysis and interpretation; preparation of a photoacoustic imaging system for clinical studies; interact and interface with clinical partners at the Johns Hopkins Hospital

Preferred Background & Skills:
Ability to perform laboratory experiments and analyze results; programming experience in MATLAB; experience with ultrasound imaging, lasers, optics, and/or programming experience in C/C++ or Python would be helpful, but not required.

2020 REU Projects

Project 3: Photoacoustic-Based Visual Serving of Surgical Tool Tips
Mentor: Professor Muyinatu Bell

Project Description:
In intraoperative settings, the presence of acoustic clutter and reflection artifacts from metallic surgical tools often reduces the effectiveness of ultrasound imaging and complicates the localization of surgical tool tips. This project explores an alternative approach to tool tracking and navigation in these challenging acoustic environments by augmenting ultrasound systems with a light source (to perform photoacoustic imaging) and a robot (to autonomously and robustly follow a surgical tool regardless of the tissue medium). The robotically controlled ultrasound probe will continuously visualize the location of the tool tip by segmenting and tracking photoacoustic signals generated from an optical fiber inside the tool.

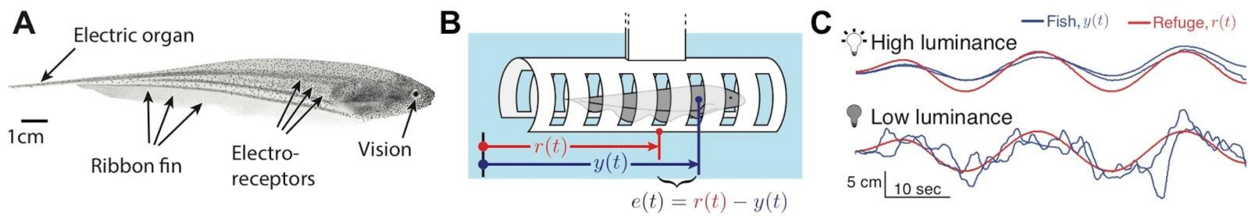
Role of REU Student:
System validation in the presence of multiple tissue types; hands-on experiments with an integrated robotic-photoacoustic imaging system; data analysis and interpretation

Preferred Background & Skills:
Ability to perform laboratory experiments and analyze results; programming experience in MATLAB; programming experience in C/C++ and Python; experience with ultrasound imaging, lasers, and/or optics, would be helpful, but not required.

Project 4: Closed-Loop Control of Active Sensing in Biological Systems
Mentor: Professor Noah J. Cowan

Project Description:
Active Sensing is the expenditure of energy---often in the form of movement---for the purpose of sensing. For example, when you sense the texture of an object, versus estimating its weight, you perform different hand motions. These specialized “active” hand movements match the properties of the very different types of sensory receptors used for each specific task. Our goal is to analyze such active sensing behavior in a uniquely suited animal, the weakly electric fish (Fig. 1A). These fish produce and detect electric fields (i.e. "electrical sonar"). This fish perform a “hiding behavior” where they swim back and forth to stay hidden inside a refuge (Fig. 1B). In the dark, they “shimmy” backward and forward (analogous to moving your hand on a surface) to enhance the sensory input to their electrical sensors (Fig. 1C). Our goal is to develop quantitative mathematical models of active sensing so that we can translate the ideas of active sensing in a rigorous way, into algorithms that could be implemented by a robotic system.

2020 REU Projects



Role of the student:
The REU student will be involved in biological experimentation using our custom-real-time, closed loop experimental system. In addition, he or she will perform data analysis, system programming, and mathematical modeling of active sensing behavior.

Helpful Skills:
Undergraduate training in linear algebra and differential equations. Some knowledge of dynamical systems and control theory is highly desirable. Also, knowledge of Matlab or another language (C, C++, Python). No specific experimental background in biological systems is required, but a lack of fear of getting into the lab (with mentorship) and performing non-invasive behavior experiments on live animals (specifically, fish) is essential. Relevant paper: D. Biswas, L. A. Arend, S. A. Stamper, B. P. Vágvölgyi, E. S. Fortune, and N. J. Cowan, "Closed-Loop Control of Active Sensing Movements Regulates Sensory Slip," Curr Biol, vol. 28, iss. 4, 2018.

Project 5: Extracting Markers of Emotion in Human Speech
Mentor: Professor Archana Venkataraman

Project Description:
Emotion is the cornerstone of human social interactions, yet it still eludes modern-day Artificial Intelligence. One of the biggest roadblocks to developing emotionally aware AI is that we lack a comprehensive model of emotional speech. This project aims to bridge this gap by isolating the features of human speech that convey emotion. These features can be linked to the underlying signal characteristics (pitch, intensity, rhythm), the linguistic content, and speaking style. This project will also link perceptual variability to underlying demographic factors to quantify the "emotional salience" of each utterance.

Role of the student:
The goals of this project include but are not limited to:

a. Develop and implement machine learning algorithms for emotion recognition; this task may require the use of deep learning architectures
b. Identify statistical differences in human emotional perception based on gender, sentence structure, and linguistic content.

2020 REU Projects

Helpful Skills:
Students should have a solid mathematical foundation (calculus, linear algebra, and statistics) and experience with MATLAB or Python. Knowledge of signal processing and machine learning is preferred but not required.

Project 6: Predicting Neurological Deficit from Functional MRI Data

Mentor: Professor Archana Venkataraman

Project Description:
Neurological and neuropsychiatric disorders affect millions of people worldwide and carry a tremendous societal cost. Despite ongoing efforts, we have a bare-bones understanding of these disorders, and hence, a limited ability to treat them. The goal of this project is to identify predictive biomarkers of schizophrenia and spinal cord injury from functional MRI data. Students will use and potentially refine a machine learning algorithm that has been developed in the lab to predict behavioral symptoms and genetic risk. The project will involve close collaborations on the medical campus.

Role of the student:

The goals of this project include but are not limited to:

a. Adapt our machine learning pipeline to predict the level of paralysis in spinal cord injury using fMRI data.
b. Refine our existing algorithms to correlate brain activation to genetic risk for schizophrenia

Helpful Skills: Students should have a solid mathematical foundation (calculus, linear algebra, and statistics) and experience with MATLAB or Python. Knowledge of signal processing and machine learning is preferred but not required.

Project 7: System to observe and control a simplistic robot traversing an obstacle field

Mentor: Professor Chen Li

Project Description:
A main challenge that has prevented robots from moving as well as animals in complex terrain is our lack of understanding of how to make use of physical interaction between animals and robots (locomotors) and the surrounding terrain. Currently the primary approach of robot locomotion in complex environments is to avoid obstacles (e.g., self-driving cars) simply relying on environment geometry. However, for robots dynamically moving through complex terrain with many large obstacles, such as forest floor or earthquake rubble, it is impossible to always avoid obstacles. Instead, making use of physical interaction with obstacles becomes essential. This project is part of our ongoing research to develop and use robotic systems to study how to make use of physical interaction to traverse complex terrain.

Role of the student: The REU student will lead the development and systematic testing of the system.

Helpful Skills: Integrating sensors and actuators, automation, feedback control, mechatronics, microcontroller, LabVIEW, MATLAB, C++, Robot Operating System, CAD design, 3D printing, machining, IMU / force sensors, circuit design, signal communication. For more information, visit https://li.me.jhu.edu/

Project 8: Feature Computation Methods in Optical Coherence Tomography Angiography

Mentor: Professor Jerry Prince and Yihao Liu

Project Description:
Retinal optical coherence tomography (OCT) is becoming an important tool in the diagnosis and management of neurological diseases. OCT angiography (OCTA), a new tool based on the same underlying technology, is proving to be a rich source of data on the condition of the vessels in the retina. It is challenging however, to compute accurate and reproducible image features from these images.

Role of the student:

The REU student will investigate new features that can be computed from OCTA data and will analyze the reliability of these computed features.

Helpful Skills: Basic image processing, Matlab, Python, and prior exposure to deep convolutional neural networks.

Project 9: Accurate Computation of Intracranial Volume from Magnetic Resonance Images

Mentor: Professor Jerry Prince and Shangxian Wang

Project Description:
Intracranial volume (ICV) is defined to be the volume inside the cranium; it is often used to normalize volumetric measurements of brain volume for better understanding of normal aging and the impact of disease on brain volume. Methods to measure ICV from magnetic resonance images (MRI), however, have been challenging because bone is typically invisible on conventional MRI. As a result, ICV has been often computed as a fixed multiple of the combined volumes of the brain parenchyma and cerebrospinal fluid. This project seeks a better measurement through synthesis of computed tomography images from MRI. This new technology, which is a direct result of the new capabilities of machine learning and in particular deep convolutional neural networks, enables a new ICV measurement approach that requires further development and evaluation.

2020 REU Projects

Role of the student:

The REU student will run algorithms for CT synthesis and ICV estimation and compare their results against manual delineations. Based on these results, the REU student will implement methods to improve the processing and provide more accurate and reliable ICV measurements.

Helpful Skills: Basic image processing, Python, and prior exposure to deep convolutional neural networks.

Project 10: Colloidal Quantum Dot-Based Field Effect Transistors for Photo-sensing and Materials Characterization

Mentor: Professor Susanna Thon

Project Description:
Colloidal quantum dots (CQDs) are promising materials for technologies such as solar cells, infrared photodetectors, and flexible electronics. As such, they can be incorporated into a variety of device types, including field effect transistors, which can serve as both photo-sensors and platforms for characterizing basic CQD film optoelectronic properties. The aim of this project is to design, fabricate, and test a robust CQD-based field effect transistor architecture. The project will include chemical synthesis, device fabrication, and optical/electronic testing components.

Role of the student: The REU student will be in charge of designing and fabricating the CQD field effect transistors. Additionally, the REU student will assist graduate students with colloidal materials synthesis, optoelectronic device characterization, and data analysis.

Helpful Skills: Familiarity with Matlab is preferred. Thin-film deposition and processing skills and some experience or comfort level with wet chemistry techniques are desirable but not required. All lab skills will be taught as-needed.

Project 11: Subspace Clustering

Mentor: Professor Rene Vidal

Project Description:
Consider the task of separating different moving objects in a video (e.g., driving cars and walking people in a video clip of a street). While humans can easily solve this task, it is challenging for a computer, which sees only ordered 0's and 1's. Fortunately, this problem has a specific property that allows a computer to tackle this challenge: For all the points of the same moving object, the vectors built from their trajectories lie in a common subspace. Thus, this problem boils down to a math problem of separating different subspaces in the ambient space.

2020 REU Projects

Project Goals:
Given a set of data points that are drawn from multiple subspaces with unknown membership, we want to simultaneously cluster the data into appropriate subspaces and find subspaces fitting each group of points. This problem is known as *subspace clustering*, which has applications in, beside the motion segmentation mentioned above, image segmentation, face clustering, hybrid system identification, etc. The Vision Lab has worked extensively on this topic and has developed geometric approaches such as the Generalized Principle Component Analysis, and spectral clustering approaches such as the Sparse Subspace Clustering. The goal of the project is to further improve the algorithms for subspace clustering. Possible research directions include:

- To develop scalable algorithms that can handle data with millions of samples.
- To develop algorithms that can effectively deal with class-imbalanced data and improve clustering accuracy.
- To develop algorithms that are able to deal with missing entries in the data, e.g., incomplete trajectories in the motion segmentation applications.
- To develop algorithms than can effectively deal with data points that are drawn from high relative dimensional subspaces, e.g. hyperplanes. Specifically, the approach will be based on the Dual Principal Component Analysis framework developed by the Vision Lab.
- To develop subspace clustering algorithms based on non-convex matrix factorization. These methods are often highly scalable and robust but are more difficult to optimize.
- To extend current subspace clustering algorithms so that they can account for nonlinear structures in data. In particular, one of the approaches is to jointly learn a feature representation using deep neural networks and apply subspace clustering.

Role of the student:
As part of the project, the intern will work alongside PhD students and develop novel algorithms for subspace clustering. The intern will implement code for these algorithms as well as test them on several databases. The intern will learn necessary background knowledge in machine learning, computer vision, compressed sensing, optimization, and will read research papers on subspace clustering. Moreover, the intern will implement novel algorithms in MATLAB/Python using different datasets. The intern will present his or her work to other graduate students and professors and will potentially be able to publish the research in computer vision conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

Helpful Skills:
Strong background in linear algebra and experience in MATLAB/Python coding is a plus.

2020 REU Projects

Project 12: Understanding Deep Neural Network Training
Mentor: Professor Rene Vidal

Project Description:
Deep learning based methods have replaced traditional machine learning algorithms as the state-of-the-art in nearly every problem domain. However, our understanding of why these methods are so successful is still very limited. Why is it that bigger networks always seem to generalize better? How is stochastic gradient descent able to converge to networks with zero loss, despite the dramatic non-convexity of the learning problem? What explains the success of certain design innovations over others, e.g. rectified linear activation and batch normalization? An important goal of ongoing research in the field is to begin to address some of these puzzles.

Project Goals:
The deep learning optimization problem is highly non-convex: there exist many equivalent locally-optimal weight parameters, separated in the optimization landscape by ridges of poor parameters. This makes the process of finding good network weights a challenging combinatorial problem in principle. Interestingly however, deep network training works remarkably well in practice.

Recent theoretical work shows that if a deep network is allowed to vary in size, and the network activation is enforced to be positively homogeneous--a condition which the popular rectified linear activation satisfies--then the non-convex learning problem admits a tight convex relaxation. This suggests that for this kind of deep network, the optimization landscape, although non-convex, has nice structure enabling efficient optimization. In this project, we will investigate this hypothesis experimentally and theoretically, by studying the deep learning optimization landscapes for different network architectures, activation functions, and forms of regularization.

Role of the student:
As part of the project, the intern will work alongside PhD students to develop empirical and theoretical approaches to probe the high-dimensional deep learning optimization landscape. The intern will learn necessary background knowledge in machine learning and optimization to contribute to this research. The intern will gain experience implementing small and medium-scale deep networks using popular deep learning frameworks and evaluating their behavior. The intern will present his or her work to other graduate students and professors and will potentially be able to publish the research in machine learning conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

2020 REU Projects

Helpful Skills:
A strong background in linear algebra, optimization, and experience in MATLAB/Python coding is strongly encouraged.

Project 13: Activity Recognition
Mentor: Professor Rene Vidal

Project Description:
The human visual system is exquisitely sensitive to an enormous range of human movements. We can differentiate between simple motions (left leg up vs. right hand down), actions (walking vs. running) and activities (making a sandwich vs. making a pancake). Recently, significant progress has been made in automatically recognizing human activities in videos. Such advances have been made possible by the discovery of powerful video descriptors and the development of advanced classification techniques. With the advent of deep learning, performance in simple tasks, such as action classification, has been further improved. However, performance in recently released large-scale video datasets depicting a variety of complex human activities in untrimmed videos is well below human performance for most activity recognition methods, since scaling to thousands of videos and hundreds of action classes as well as recognizing actions in real, unstructured environments is particularly challenging.

Project Goals:
The goal of this project is to develop algorithms for recognizing human actions in unstructured and dynamically changing environments. An automatic system for human activity recognition is of particular interest in applications such as surveillance, physical therapy rehabilitation, behavioral intervention systems, surgical skill evaluation, etc. In developing such systems, one typically faces problems such as, designing models to efficiently represent actions (feature extraction), classification of short pre-segmented clips, and spatial and temporal localization of actions (segmentation). In this project, we are especially interested in designing novel activity recognition algorithms that also exploit contextual information in scenes (e.g., via modeling each image or short clip as an attributed graph that captures object interactions). This requires the design of novel graph-based action representations in videos, efficient mechanisms for data processing and fusion, and the design of appropriate discriminative metrics for learning.

Role of the student:
As part of the project, the intern will work alongside PhD students and develop novel algorithms for activity recognition tasks, such as fine-grained temporal activity segmentation and recognition and/or action detection/localization. The intern will implement code for these algorithms as well as test them on several benchmark datasets. The intern will read research papers on activity recognition and time-series

modeling, and will learn new techniques to solve the above problems. Moreover, the intern will implement novel algorithms in Python (MATLAB/C++) and become familiar with several computer vision and machine learning concepts.

The intern will present his or her work to other graduate students and professors and will potentially be able to publish the research in computer vision conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

Helpful Skills:
Experience in programming in programming (Python/MATLAB/C++) and familiarity with computer vision and basic machine learning techniques (such as Support Vector Machines, Conditional Random Fields, Hidden Markov Models and Neural Networks) is a plus.

Project 14: Accelerated Non-Convex Optimization

Mentor: Professor Rene Vidal

Project Description:
Optimization is at the core of almost every problem in machine learning and statistics. Modern applications require minimizing high dimensional functions for problems that may have polynomial complexity on the number of data points, imposing severe limits on the scalability of standard methods, such as gradient descent or other first order methods. In the 1980's Nesterov proposed a method to accelerate gradient descent which provably attains the fastest convergence possible under general assumptions, and since then this technique has been applied to several other first order algorithms. Nevertheless, the mechanism behind acceleration is still considered not well understood. Our group has recently obtained several promising results in connection to continuous dynamical systems, providing a unified perspective on acceleration methods. Moreover, from such connections, new algorithms were obtained.

Project Goals:
We want to understand known and some of the new accelerated algorithms obtained in connection to continuous dynamical systems in convex and possibly nonconvex settings. These methods will be applied to some problems of interest in machine learning such as subspace clustering, matrix factorization, matrix completion, or others. We aim at making solution methods to these problems faster and more scalable.

Role of the student:
The intern will work alongside PhD students and Postdocs, having the opportunity to learn modern research methods in optimization for machine learning and dynamical systems, besides background material in machine learning, subspace clustering, and matrix completion. The intern will implement code for accelerated optimization algorithms in Python, and run them against real datasets. The intern will present his or her work to other graduate students and professors and will potentially be able to publish the research in conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

Helpful Skills:
A strong background in undergraduate mathematics and working experience in Python or MATLAB are required.

Project 15: Development of a New Remotely Operated Underwater Vehicle: Software Development

Mentor: Professor Louis Whitcomb

Project Description:
This REU student project is to work with other undergraduate and graduate students to develop a new remotely operated underwater robotic vehicle (ROV) that will be used for research in navigation, dynamics, and control of underwater vehicles. Our goal is to develop a neutrally buoyant tethered vehicle capable of agile six degree-of-freedom motion with six marine thrusters, and to develop new navigation and control system software using the open-source Robot Operating System (ROS).

Role of the student:
We seek a student to assist in the development of software to interface with a variety of sensors and control units relevant to underwater navigation in order to make them compatible within a ROS (Robotic Operating System) framework, and integrated within a system that facilitates the navigation and control of an underwater vehicle.

Helpful Skills:

Required:

- Intermediate C++
- Git
- Familiarity using and maintaining a Linux system
- Familiarity with CMake
- Proficiency in ROS

Desired:

- Programming experience with large open-source projects

- Python

Project 16: Development of a New Remotely Operated Underwater Vehicle: Electrical Development

Mentor: Professor Louis Whitcomb

Project Description:
This REU student project is to work with other undergraduate and graduate students to develop a new remotely operated underwater robotic vehicle (ROV) that will be used for research in navigation, dynamics, and control of underwater vehicles. Our goal is to develop a neutrally buoyant tethered vehicle capable of agile six degree-of-freedom motion with six marine thrusters, and to develop new navigation and control system software using the open-source Robot Operating System (ROS).

Role of the student:
We seek a student to assist in the design and manufacturing of various electrical systems of a new underwater vehicle. The work would include improving upon current power distribution circuit designs and integrating various sensors and actuators into the vehicle system.

Helpful Skills:

Required

- Knowledge of analog, digital electronics theory and applications
- Experience using schematic/circuit design software
- Embedded microprocessor programming
- Multilayer board fabrication/manufacturing skills, including through-hole and SMD
- Competent with oscilloscope and benchtop power supply

Desired

- C/C++
- Proficiency in Kicad
- Knowledge of power electronics

2020 REU Projects

Project 17: Development of a New Remotely Operated Underwater Vehicle: Mechanical Development

Mentor: Professor Louis Whitcomb

Project Description:
This REU student project is to work with other undergraduate and graduate students to develop a new remotely operated underwater robotic vehicle (ROV) that will be used for research in navigation, dynamics, and control of underwater vehicles. Our goal is to develop a neutrally buoyant tethered vehicle capable of agile six degree-of-freedom motion with six marine thrusters, and to develop new navigation and control system software using the open-source Robot Operating System (ROS).

Role of the student:
We seek a student to assist in the design and manufacturing of the mechanical systems of a new underwater vehicle. This work would include improving upon current pressure housing designs & overall vehicle designs as well as coordinating the manufacturing of parts and performing simple assembly/manufacturing tasks as needed.

Helpful Skills:

Required:

- Proficiency in CAD
- Mechanical fabrication and machining skills
- Knowledge of basic electronics and instrumentation

Desired:

- Proficiency in Solidworks
- Knowledge of heat transfer, fluid dynamics

Project 18: Telerobotic System for Satellite Servicing

Mentor: Professors Peter Kazanzides, Louis Whitcomb and Simon Leonard

Project Description:
With some satellites entering their waning years, the space industry is facing the challenge of either replacing these expensive assets or to develop the technology to repair, refuel and service the existing fleet. Our goal is to perform robotic on-orbit servicing under ground-based supervisory control of human operators to perform tasks in the presence of uncertainty and time delay of several seconds. We have successfully demonstrated telerobotic removal of the insulating blanket flap that covers the spacecraft’s fuel access port, in ground-based testing with software-imposed time delays of several seconds.

2020 REU Projects

Role of the student:
The student will assist with this ongoing research, including the development of enhancements to the mixed reality user interface, experimental studies, and extension to other telerobotic operations in space.

Helpful Skills:
Ability to implement software in C/C++, familiarity with ROS, good lab skills to assist with experiment setup, and ability to analyze experimental results.

Project 19: Software Framework for Research in Semi-Autonomous Teleoperation

Mentor: Professors Peter Kazanzides and Russell Taylor

Project Description:
We have developed an open source hardware and software framework to turn retired da Vinci surgical robots into research platforms (da Vinci Research Kit, dVRK) and have disseminated it to 35 institutions around the world. The goal of this project is to contribute to the advancement of this research infrastructure.

Role of the student:
The specific task will take into account the student's background and interests, but may be one of the following: (1) 3D user interface software framework, (2) data collection tools and protocols to support machine learning, (3) integration of alternative input devices and/or robots, or (4) development of dynamic models and simulators.

Helpful Skills:
Student should have experience with at least one of the following programming environments: C/C++, Python, ROS.

Project 20: Augmented Reality Head Mounted Display for Surgery

Mentor: Professor Peter Kazanzides and Ehsan Azimi

Project Description:
We have developed an augmented reality surgical navigation system by taking advantage of the tracking and visualization capabilities of an optical see-through head mounted display (HMD). Our initial application is ventriculostomy, which is a bedside neurosurgical procedure where a catheter is inserted into the brain ventricles to relieve pressure by draining cerebrospinal fluid.

Role of the student:
The goal of this project is to apply this system to other types of surgical procedures, which may include the integration of external tracking systems.

Helpful Skills:
Student should have experience with the Unity 3D environment, including programming in C#, and the ability to construct phantoms, perform experiments, and analyze data. Knowledge of C/C++ or Python may be helpful.

Project 21: Haptic Feedback and Control for Upper-Limb Prosthetic Devices
Mentor: Professor Jeremy D. Brown

Project Description:
Individuals with an upper-limb amputation generally have a choice between two types of prostheses: body-powered and externally-powered. Body powered prostheses use motion in the body to generate motion of the prosthetic gripper by means of a cable and harness system that connects the body to the device. In this way, body-powered prostheses feature inherent haptic feedback: what is felt in the gripper gets transmitted through the cable to the harness. Externally-powered prostheses come in many forms, however, most utilize electromyography (EMG) for controlling the prosthetic gripper. Since this control input is electrical, there is no mechanical connection between the body and the prosthetic gripper. Thus, myoelectric EMG-based prostheses do not feature haptic feedback and amputees who wear them are currently unable to feel many of the physical interactions between their prosthetic limb and the world around them. We have previously shown that prostheses with lower mechanical impedance allow for a high degree of naturalistic control, and that haptic force feedback of grip force provides more utility than vision in an object recognition task. This project seeks to build on these previous findings by investigating the entire sensorimotor control loop for upper-limb prostheses. The research objective of this project is to test the hypothesis that sensory feedback and control requirements for upper-limb prosthesis function will be task specific.

Role of the student:
With supportive mentorship, the REU student will lead the refinement and evaluation of our current mock upper-limb prosthesis experimental apparatus, which involves mechanical, electrical, and computational components. He or she will then work closely with clinical partners to design, conduct, and analyze a human-subject experiment to evaluate specific aspects of the overarching research hypothesis.

Helpful Skills:
Experience with CAD, Matlab, and/or C++ would be beneficial. Interest in working collaboratively with both engineering and clinical researchers. Mechatronic design experience and human-subject experiment experience would be helpful but are not required.

2020 REU Projects

Project 22: Bimanual Haptic Feedback for Robotic Surgery Training

Mentor: Professor Jeremy D. Brown

Project Description:
Robotic minimally invasive surgery (RMIS) has transformed surgical practice over the last decade; tele-operated robots like Intuitive Surgical's da Vinci provide surgeons with vision and dexterity that are far better than traditional minimally invasive approaches. Current commercially available surgical robots, however, lack support for rich haptic (touch-based) feedback, prohibiting surgeons from directly feeling how hard they are pressing on tissue or pulling on sutures. Expert surgeons learn to compensate for this lack of haptic feedback by using vision to estimate the robot's interactions with surrounding tissue. Yet, moving from novice proficiency to that of an expert often takes a long time. We have previously demonstrated that tactile feedback of the force magnitude applied by the surgical instruments during training helps trainees produce less force with the robot, even after the feedback is removed. This project seeks to build on these previous findings by refining and evaluating a bimanual haptic feedback system that produces a squeezing sensation on the trainee's two wrists in proportion to the forces they produce with the left and right surgical robotic instruments. The research objective of this project is to test the hypothesis that this bimanual haptic feedback will accelerate the learning curve of trainees learning to perform robotic surgery. In addition, this project seeks to use haptic signals to objectively measure and eventually improve skill at robotic surgery.

Role of the student:
With supportive mentorship, the REU student will lead the refinement and evaluation of our current haptic feedback system, which involves mechanical, electrical, and computational components. He or she will then work closely with clinical partners to select clinically appropriate training tasks and will design, conduct, and analyze a human-subject experiment to evaluate the system.

Helpful Skills:
Experience with CAD, Matlab, and/or Python would be beneficial. Interest in machine learning and in working collaboratively with both engineering and clinical researchers. Mechatronic design experience and human-subject experiment experience would be helpful but are not required.

Project 23: Wearable Networked Devices for Detecting Motion of Patients in Coma

Mentor: Professor Ralph Etienne Cummings

Project Description:
This project will involve the miniaturization of a wearable device that will allow the monitoring of patients in the intensive care unit (ICU). The devices will monitor the

movements of patients while in coma. Machine learning algorithms will be used to determine if the patients show sign of recovery and emergence from coma.

Helpful Skills:
Hardware, firmware and software design skills. Experience with Bluetooth networking and PCB design are bonuses.

Project 24: Robotic System for Mosquito Dissection
Mentors: Professor Russell Taylor and Professor Iulian Iordachita

Project Description:
We have an ongoing collaboration with Sanaria, Inc. to develop a robotic system for extracting salivary glands from *anopheles* mosquitoes, as part of a manufacturing process for a clinically effective malaria vaccine that is being developed by Sanaria. This project combines computer vision, real time programming, robotics, and novel mechanical design aspects. The specific task(s) will depend on the student(s) background, but may include: 1) real time computer vision; 2) machine learning for vision; 3) real time robot programming; 4) mechanical design; 5) system testing and evaluation. Depending on the project and progress, there will be opportunities to participate in academic publication and possible further patenting.

Preferred Background Skills:
For software, robot programming, or vision projects, the student(s) should have experience with Python. In addition, experience with vision and/or deep learning will be needed for vision-oriented projects. For mechanical design, students should have significant experience with mechatronic design, CAD, 3D printing and other fabrication processes. Experience with computer interfaces and low-level control (e.g., with Arduino-type subsystems) may also be useful.

Project 25: Instrumentation and steady-hand control for new robot for head-and-neck surgery
Mentor: Professor Russell Taylor

Description:
We have an active collaboration with Galen Robotics, which is commercializing a “steady hand” robot developed in our laboratory for head-and-neck microsurgery. In “steady hand” control, both the surgeon and the robot hold the surgical instrument. The robot senses forces exerted by the surgeon on the tool and moves to comply. Since the motion is actually made by the robot, there is no hand tremor, the motion is very precise, and “virtual fixtures” may be implemented to enhance safety or otherwise

improve the task. Potential applications include endoscopic sinus surgery, transphenoidal neurosurgery, laryngeal surgery, otologic surgery, and open microsurgery. While the company is developing the clinical version of the robot, we have active on-going research to develop novel applications for the system.

Possible projects include:

- Development of “phantoms” (anatomic models) for evaluation of the robot in realistic surgical applications.
- User studies comparing surgeon performance with/without robotic assistance on suitable artificial phantoms.
- Optimization of steady-hand control and development of virtual fixtures for a specific surgical application
- Design of instrument adapters for the robot
- Developing interfaces to surgical navigation software

Required Skills:
The student should have a background in biomedical instrumentation and an interest in developing clinically usable instruments and devices for surgery. Specific skills will depend on the project chosen. Experience in at least one of robotics, mechanical engineering, and C/C++ programming is important. Similarly, experience in statistical methods for reducing experimental data would be desirable.

Project 26: Accuracy Compensation for “Steady Hand” Cooperatively Controlled Robots
Mentor: Professor Russell Taylor

Description:
Many of our surgical robots are cooperatively controlled. In this form of robot control, both the robot and a human user (e.g., a surgeon) hold the tool. A force sensor in the robot’s tool holder senses forces exerted by the human on the tool and moves to comply. Because the robot is doing the moving, there is no hand tremor, and the robot’s motion may be otherwise constrained by virtual fixtures to enforce safety barriers or otherwise provide guidance for the robot. However, any robot mechanism has some small amount of compliance, which can affect accuracy depending on how much force is exerted by the human on the tool. In this project, the student will use existing instrumentation in our lab to measure the displacement of a robot-held tool as various forces are exerted on the tool and develop mathematical models for the compliance. The student will then use these models to compensate for the compliance in order to assist the human place the tool accurately on predefine targets. We anticipate that the results will lead to joint publications involving the REU student as a co-author.

2020 REU Projects

Required Skills:
The student should be familiar with basic laboratory skills, have a solid mathematical background, and should be familiar with computer programming. Familiarity with C++ would be a definite plus, but much of the programming work can likely be done in MATLAB or Python.