2021 CSMR REU Project Descriptions

Project Name 1: Telerobotic System for Satellite Servicing
PI: Peter Kazanzides, Louis Whitcomb and Simon Leonard
Mentor: Peter Kazanzides

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.

Role of REU 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.

Required Background & Skills:
Programming skills in C/C++ or Python or C#

Preferred Background & Skills:
Familiarity with ROS or Unity, good lab skills to assist with experiment setup, and ability to analyze experimental results

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Project Name 2: Software Framework for Research in Semi-Autonomous Teleoperation
PI: Peter Kazanzides, Russell Taylor
Mentor: Anton Deguet

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 39 institutions around the world. The goal of this project is to contribute to the advancement of this research infrastructure.

Role of REU 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) improved teleoperation (e.g., joint limits), (3) PSM to ECM registration, or (4) integration of alternative input devices and/or robots.

Required Background & Skills:

Programming skills in C/C++ or Python

Preferred Background & Skills:
Programming skills in C/C++ and Python, and experience with ROS

Project Name 3: Deep Learning Based Brain Motion Modelling
PI: J.L. Prince
Mentor: A. Alshareef

Project Description: Traumatic brain injury (TBI) results from a rapid change in the external forces applied to the head. TBI is a major cause of death and disability worldwide. Understanding how the severity and type of TBI event and ultimately affect the brain is poorly understood and an area of developing research. Existing work in the field has focused on using finite element models (FEMs) to identify the influence of the TBI on the subject. FEMs have two drawbacks in this regard: 1) they are not patient specific; 2) they are computational intensive.

Role of REU Student: Take existing FEMs and use them to train deep networks to simulate the FEM outcomes. With a trained network the REU Student will then test its predictive abilities in various settings. Initial work would focus on a physical phantom that can be more readily observed under various loading conditions. The ultimate goal being to use the network to model subject-specific behavior similar to real world TBIs.

Required Background & Skills: Background in mechanical engineering, computer science, biomedical engineering or related fields. Programming in Python and experience with Deep Networks.

Preferred Background & Skills: Exposure to Biomechanical concepts is useful, including some familiarity with finite element models.

Project Name 4: Comparing Statistical and Image Based Harmonization
PI: J.L. Prince
Mentor: Lianrui Zuo

Project Description: Magnetic resonance (MR) images do not have a standardized intensity scale, which means that it is hard to compare images that are acquired at different times or on different scanners. There are now myriad ways in which MR images can be placed on a common scale (or harmonized). These include purely statistical approaches and more recently image based disentangling methods. The two approaches vary in their needs and benefits.

Role of REU Student: This project is focused on a “King of the Mountain” style competition between these two harmonization frameworks. We are interested in determining the best use case for each of these frameworks but also on the performances of various methods in each category (COMBAT for statistical and CALAMATI for image based harmonization).

Required Background & Skills: Basic image processing, Python, and prior exposure to deep convolutional neural networks. Understanding of statistics.

Project Name 5: Optimal Tissue Contrast in MR Imaging
PI: J.L. Prince
Mentor: Lianrui Zuo

Project Description: Magnetic resonance (MR) imaging is a versatile imaging modality that is highly tunable based on the selected imaging parameters. As such it suffers from a medical version of FOMO: a priori clinicians may not know what they are looking for. There has been ongoing work on using disentangling-based deep networks to differentiate image contrast and brain structure. Previous work with such networks has focused on harmonizing the MR images—essentially make them have a similar contrast appearance—this work looks to identify unique contrasts that are task specific.

Role of REU Student: The basic disentangling network has been developed, we would like to extend the network to back-propagate losses to identify optimal contrasts for identify various brain structures; Or contrasts that are optimal for various downstream image processing tasks.

Required Background & Skills: Experience with training and modifying deep networks in Python.

Project Name 6: Super-Resolution of Optical Coherence Tomography Angiography Images
PI: J.L. Prince
Mentor: Yihao Liu and Samuel Remedios

Project Description: Retinal optical coherence tomography (OCT) is becoming an important tool in the diagnosis and management of neurological diseases. OCT angiography (OCTA) is a new imaging modality that is based on the same underlying technology as OCT. OCTA is proving a rich source of data for understanding the condition of the vessels of the human retina. Unfortunately, a large amount of data being collected today is of a low-resolution (LR); due to patient motion and the imaging platform in use, it is not always possible to acquire a high-resolution (HR) OCTA image.

Role of REU Student: Recently developed super-resolution (SR) deep networks have been used to improve the resolution of magnetic resonance images. This, coupled with our acquisition of paired HR and LR makes it feasible to train a SR deep network for OCTA. The project will be focused on the evaluation and performance characteristics of such a deep network.

Required Background & Skills: Basic image processing, Matlab, Python, and exposure to deep networks.

Project Name 7: Bimanual Haptic Feedback for Robotic Surgery Training

PI: Prof. Jeremy D. Brown
Mentor: TBD

Project Description: Robotic minimally invasive surgery (RMIS) has transformed surgical practice over the last decade; teleoperated 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 and vibrotactile feedback of the instrument vibrations. 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 REU 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.

Required Background & Skills: Experience with CAD, rapid prototyping, MATLAB/Simulink, and Python. Interest in working collaboratively with both engineers and clinicians.

Preferred Background & Skills: Mechatronic design experience and human-subject experiment experience, and experience with ROS.

Project Name 8: Haptic Feedback and Control for Upper-Limb Prosthetic Devices
PI: Prof. Jeremy D. Brown
Mentor: TBD

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 develop fundamental insights into amputee-prosthesis co-adaptation through novel control and feedback strategies.

Role of REU 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.

Required Background & Skills: Experience with CAD, rapid prototyping, MATLAB/Simulink. Interest in working collaboratively with both engineers and clinicians.

Preferred Background & Skills: Mechatronic design experience and human-subject experiment experience.

Project Name 9: Spray-Cast Manufacturing of Nanomaterials for Flexible Sensing and Power Generation
PI: Susanna Thon
Mentor: Lulin Li

Project Description: Colloidal quantum dots (CQDs) and related nanomaterials are promising platforms for technologies such as solar cells, infrared photosensors, and portable electronics. Due to their solution-processed nature, they can be incorporated into scalable manufacturing processes and flexible devices. The aim of this project is to develop spray-cast fabrication methods for flexible solar cells and sensors that can be integrated into portable energy storage systems and other next-generation mobile electronics. The project will include chemical synthesis, computer-aided design, device fabrication, and optical/electronic testing components.

Role of REU Student: The REU student will be in charge of optimizing spray-casting techniques for CQD solar cells and sensors, including instrument design and upgrades. Additionally, the REU student will assist graduate students with colloidal materials synthesis, optoelectronic device characterization, and data analysis.

Required Background & Skills: Familiarity with Matlab and some wet chemistry experience (basic chemical safety).

Preferred Background & Skills: CAD experience is desirable but not required. All lab skills will be taught as-needed.

Project Name 10: Design of Amphibious Fish Robots to Traverse Deformable Substrate and Tall Vegetation
PI: Chen Li
Mentor: Qiyuan Fu

Project Description:
Demands of amphibious robots are arising in applications such as environmental monitoring and sewage inspection. However, few robots have succeeded in traversing complex amphibious environments, especially those with deformable substrates and tall vegetation, which are common at the water-land boundary such as marsh flats. This is because little is understood about the physical interaction between the robot and such environments. Many previous studies focused on either only kinematics of amphibious fish traversing such environments, or amphibious locomotion transitioning between flat, rigid ground and aquatic environments. It is not yet clear how forces emerge from the interaction with deformable substrates and vegetation and how to utilize them. To elucidate this, this project will design amphibious fish robot prototypes to traverse model terrain systems with thick mud and elastic rods. The robots will have morphologies that can be configured for different locomotion strategies and force sensors instrumented to measure interaction forces for modeling or feedback control.

Role of REU Student:
The REU student will design the robots with the supervision of the PI and the mentor.

Required Background & Skills:
Strong mechatronics skills, including CAD design, 3D printing, machining, microcontroller programming, experience using sensors (IMU/force sensors/cameras) and actuators (servo motors/linear actuators).

Preferred Background & Skills:
Feedback control, MATLAB, Robot Operating System, circuit design, signal processing.

Project Name 11: How does the brain respond to altered sensorimotor feedback?
PI: Noah Cowan
Mentor: Yu Yang

Project Description: When we turn our eyes to the right, it creates an equal-and-opposite shift of the visual world on our retina. We can use this so-called "reafferent feedback" to help stabilize an image on our fovea. Small errors caused by moving a bit too far, or not far enough, create a "visual error" that our brains can use to readjust our motor output. In this project, we will investigate a very similar sensorimotor loop, but in an animal model system, the weakly electric glass knifefish *Eigenmannia virescens.* These fish naturally swim back and forth to track a moving refuge (a plastic tube) in much the same way that we move our eyes back and forth to track a visual target. The analysis of how the fish converts sensory inputs into motor output therefore can give us general insights into sensorimotor control. In particular, *Eigenmannia* generates active sensing movement during tracking for the purpose of acquiring sensory information. In a previous study in our lab (Biswas et al., 2018), a real time control system was developed to modulate the "gain" of this sensory feedback by modifying the movement of the refuge based on the fish's motion. In this project, the REU student will further study how the modulated reafferent feedback gain affects fish tracking performance. Preliminary results suggest that there is a change of the fish’s frequency response function (FRF) under different feedback and luminance ("visual brightness") conditions. Our goal of this project is to complete the experiments and analysis of this behavior, and uncover the biological significance of this change in the feedback controller.

Role of REU Student: The REU student will run new experiments with the fish, analyze data in Matlab and write up the results for presentation. A reasonable goal will be to present the work at the annual meeting of the Society of Integrative and Comparative Biology.

Required Background & Skills: Knowledge of linear algebra and differential equations, and proficiency with Matlab. No prior biological knowledge is required.

Preferred Background & Skills: A signals and systems or control systems course.

Project Name 12: Deep Learning to Improve Ultrasound and Photoacoustic Image Quality
PI: Professor Muyinatu Bell
Mentor: TBD

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 Name 13: Photoacoustic-Guided Surgery

PI: Professor Muyinatu Bell

Mentor: TBD

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.

Project Name 14: Photoacoustic-Based Visual Serving of Surgical Tool Tips
PI: Professor Muyinatu Bell
Mentor: TBD

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 Name 15: Robotic System for Mosquito Dissection
PIs: Professor Russell Taylor and Professor Iulian Iordachita
Mentor: TBD

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 Name 16: Instrumentation and steady-hand control for new robot for head-and-neck surgery
PIs: Professor Russell Taylor
Mentor: TBD

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 Name 17: Accuracy Compensation for "Steady Hand" Cooperatively Controlled Robots
PIs: Professor Russell Taylor
Mentor: TBD

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.

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.

Project Name 18: Autonomous Quadcopter Flying and Swarming
PI: Prof. Enrique Mallada
Mentor: Yue Shen
Resources: **https://store.bitcraze.io**

Project Description:

The recent confluence of control, robotics, and machine learning has led to algorithms with the capacity for dexterous maneuvering and sophisticated coordination. However, existing learning techniques require massive computation in offline/virtual environments. Our lab broadly aims to develop learning algorithms suitable for training in the physical environment with safety guarantees. With this aim, we seek to build a validation platform for testing algorithms for autonomous systems developed by the lab. In particular, this project aims to create a testing platform for testing autonomous quadcopter flying and swarming.

Role of REU Student:
The student will assist with several tasks developing and testing algorithms for quadcopter swarm coordination.

Preferred Background & Skills:
The student should have technical experience in calculus, differential equations, and preferably control. The student should have practical experience with at least one of the following programming environments: C/C++, Python, ROS.

Project Name 19: Autonomous Car Racing
PI: Prof. Enrique Mallada
Mentor: Tianqi Zheng
Resources: **https://f1tenth.org**

Project Description:
The recent confluence of control, robotics, and machine learning has led to algorithms with the capacity for dexterous maneuvering and sophisticated coordination. However, existing learning techniques require massive computation in offline/virtual environments. Our lab broadly aims to develop learning algorithms suitable for training in the physical environment with safety guarantees. With this aim, we seek to build a validation platform for testing algorithms for autonomous systems developed by the lab. In particular, this project aims to create a testing platform for testing autonomous car racing.

Role of REU Student:
The student will assist with several tasks including, hardware assembly, algorithm development, and testing and validation.

Preferred Background & Skills:
The student should have technical experience in calculus, differential equations, and preferably control. The student should have practical experience with at least one of the following programming environments: C/C++, Python, ROS.

Project Name 20: Development of a Wearable System to Monitor Patients Post-Op in and out of the Hospital
PI: Prof. Ralph Etienne-Cummings
Mentor: TBD

Project Description:
No system exists to inform clinicians of a quantitative level of consciousness at the bedside. The best clinically accepted practice is bedside observational assessment (GCS, CSR-R, etc).

To design, fabricate and iteratively test a wearable sensing device employing multiple modalities to continuously monitor and wirelessly transmit biological and physiological information that signify changes in the neurological state of healthy control subjects. The design of this sensor will allow for its placement on multiple sites across the body instead of a single specialized location. This design will facilitate the use of multiple copies of the sensor simultaneously in different locations to access a wide range of information across the body on the patient's health.

Required Skills:
Electronics hardware design and testing, soft/firmware development

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Project Name 21: Computational Lightfield Ophthalmoscope

PI: Nicholas J. Durr
Mentor: Marisa M. Morakis

Project Description: This project aims to create a new computational imaging technology that improves ocular fundoscopy. This new approach could make retinal images easier to acquire with synthetic depth-of-focus enhancement, aberration corrections, and large fields of view.

Role of REU Student: The REU student will work closely with a Ph.D. student (Marisa) to design the optical system, calibrate it with point sources, develop computational reconstruction algorithms, and acquire data from eye models.

Required Background & Skills: REU student should have programming and instrumentation experience and a desire to learn optics and image reconstruction techniques.

Preferred Background & Skills: A background in electrical or biomedical engineering is desirable. Skills in electronics, python, and solidworks would be valuable. Experience in machine learning would also be useful but is not required.