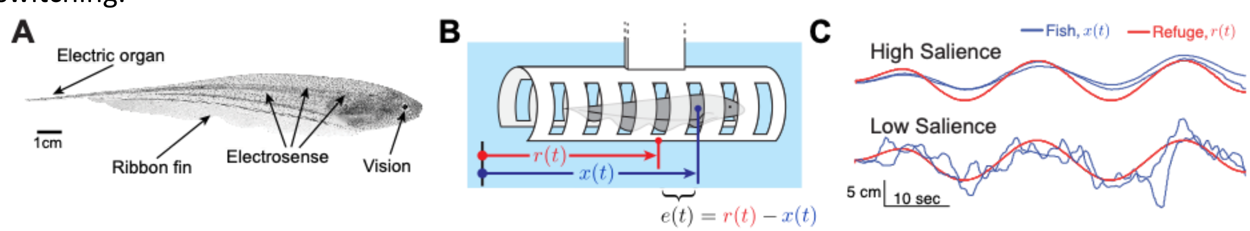
CSMR REU 2026 Project Form

1. Computational Mechanisms for State-driven Active Sensing

PI: Noah J. Cowan
Mentor: Debojyoti Biswas

Project Description: We recently showed that animals—from humans to nematodes—rapidly switch between two distinct behavioral modes during station-keeping tasks (Biswas et al., *Nature Machine Intelligence*, 2023). (1) In "exploit" mode, animals use sensory feedback to achieve a behavioral goal (such as standing upright), similar to a robotic servomechanism that corrects positional error with feedback. (2) In "explore" mode, animals produce active sensing movements (such as purposefully swaying from side to side during balance) to sense more accurately their body posture or position within the environment. Critically, the active sensing mode *increases* positional error in the short term but sharply improves the actionable state information available to the animal to achieve its behavioral goal. The REU student will work with a multidisciplinary team of engineers, mathematicians, and neuroscientists to assess the role of uncertainty and feedback in mode switching behavior using an augmented reality (AR) system developed at Hopkins. Using this system, the REU student will create extended time series datasets of weakly electric fish performing station keeping under a wide range of sensory conditions in order to determine the behavioral mechanisms of within-mode control and mode switching.



(A) The weakly electric glass knifefish, *Eigenmannia virescens,* is a uniquely suited animal system for the study of active sensing. (B) The fish maintain their position inside a longitudinally moving refuge. (C) *Eigenmannia* (blue) track a moving refuge (red) well in the high sensory salience (in the light) and low sensory salience (in the dark), but in the low salience, they produce large active swimming movements superimposed on the tracking behavior.

Role of REU Student: The REU student will (i) run new experiments with the fish, (ii) analyze data in MATLAB, (iv) communicate their ideas to a broader scientific team during biweekly meetings, and (iii) 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: Undergraduate courses in Differential Equations and Linear Algebra (or a combined LA/DE course), basic knowledge of Matlab and/or Python. No formal coursework in biology is required, but the student should be curious about the analysis of animal movement and control from an engineering perspective.

Preferred Background & Skills: Courses in any of the following would be useful, but not required: probability or statistics, system dynamics, or signals and systems.

2. Photoacoustic-Guided Surgery

PI: Prof. 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.

3. Haptic Feedback, Control, and Design for Upper-Limb Prosthetic Devices

PI: Prof. Jeremy D. Brown
Mentor: Lorena Velasquez

Project Description: Haptic (touch) feedback is essential for dexterous manipulation. Individuals with upper-limb loss who utilize myoelectric EMG-based prostheses do not receive haptic feedback when operating their device. Thus, myoelectric EMG-based prosthesis wearers 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 many tasks. 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 will be worn by non-amputee participants. He/she/they 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, ROS, Python

4. Vision-based safety mechanism for robot-assisted minimally invasive endoscopic surgery

PI: Russell H Taylor
Mentor: Manish Sahu

Project Description: In minimally invasive endoscopic surgeries, surgeons rely on endoscopes to visualize the internal anatomy. Our lab has previously developed a robotic arm for controlling the endoscope. However, any involuntary endoscope movements can harm the delicate internal anatomy of the patient. This project aims to develop a video-based safety mechanism that uses endoscopic video stream to detect unexpected movements and automatically retract the endoscope along a safe, predefined trajectory. The research objective is to design, implement, and validate a functional prototype using a benchtop robotic system and a realistic nasal phantom.

Role of REU Student: Under the mentorship of engineering and clinical faculty, the REU student will lead a) development of a real-time motion estimation algorithm using endoscopic video, b) implementation of a safe motion controller that backtracks the insertion trajectory, and c) of the complete system under controlled perturbations using a nasal phantom.

Required Background & Skills: Good programming skills in Python, undergraduate courses in computer vision or related fields. No formal coursework in robotics is required, but the student should possess basic knowledge of linear algebra, coordinate frames, and kinematics. Familiarity with Linux and command line tools. Strong interest in medical robotic systems and working collaboratively with both engineers and clinicians

Preferred Background & Skills: Experience with open-source computer vision frameworks such as OpenCV or PyTorch. Familiarity with ROS and real-time robot control frameworks.