REU 2024 Project List

1. **Deep Learning to Improve Ultrasound and Photoacoustic Image Quality**
2. **Photoacoustic-Based Visual Serving of Surgical Tool Tips**
3. **Photoacoustic-Guided Surgery**
4. **Software Framework for Research in Semi-Autonomous Teleoperation**
5. **Instrumentation and steady-hand control for new robot for head-and-neck surgery**
6. **Control of tool-to-tissue interaction forces in a cooperatively controlled surgical robot**
7. **Development of "digital twin" simulation models to provide shared situational awareness for surgical robots**
8. **Haptic Feedback and Control for Upper-Limb Prosthetic Devices**
9. **Bimanual Haptic Feedback for Robotic Surgery Training**
10. **Development of a sensorized amphibious fish robot for force feedback control to traverse mud of varying strength**
11. **Autonomous Robotic Surgery**
12. **Learning-based Force Estimation for Robotic Surgery**
13. **Optimal Magnetic Resonance Imaging Parameters for AI Models**
14. **Super-Resolution of Anisotropic Magnetic Resonance Images**
15. **Optical coherence tomography (OCT) for longitudinal retinal thickness analysis**
16. **Enhancing Usability of Diffusion-Weighted MRI Acquired with Limited Directions**
17. **Refinement of deep learning based multiple sclerosis lesion segmentation using classic iterative methods**
18. **Digital EEG Marker for Epilepsy and other Mental Health Disorders**
19. **Multimodal On-body Sensor Array for Analysis of Internal**

1. Deep Learning to Improve Ultrasound and Photoacoustic Image Quality

PI: 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.

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.

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.

4. 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

5. Instrumentation and steady-hand control for new robot for head-and-neck surgery

PIs: Prof. Russell Taylor , Dr. Manish Sahu; Surgeons: Dr. Francis Creighton, Dr. Deepa Galaiya
Mentor: TBD

Project 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, skull-base 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, using a pre-clinical prototype.

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.

6. Control of tool-to-tissue interaction forces in a cooperatively controlled surgical robot

PIs: Prof. Russell Taylor, Dr. Manish Sahu; Surgeons: Dr. Francis Creighton, Dr. Deepa Galaiya
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, skull-base neurosurgery, laryngeal surgery, otologic surgery, spine 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, using a pre-clinical prototype.

Many of the contemplated applications for this robot, especially in the lateral skull base and spine, can require delicate control to tool-to-tissue interaction forces. We have developed a force-sensing surgical drill for use with the robot that enables the system to sense these forces while separating the sensed force values from the hand forces exerted by the surgeon on the drill body.

Possible projects include:

- Mechanical/mechatronic projects:
    - Development of improved designs for the drill holder providing for improved ergonomics or sensing.
    - Development of drill-mounted surgeon interaction inputs (e.g., buttons,

sliders, etc.) to enhance the control options available to the surgeon while using the robot.

- Control enhancements to enhance the surgeon's ability to control tool-to-tissue interaction forces.
- User studies comparing surgeon performance with/without robotic assistance on suitable artificial phantoms.

Required Skills:
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.

7. Development of "digital twin" simulation models to provide shared situational awareness for surgical robots

PIs: Prof. Russell Taylor, Dr. Adnan Munawar, Prof. Mathias Unberath, Dr. Manish Sahu; Surgeons: Dr. Francis Creighton, Dr. Masaru Ishii
Mentor: TBD

Description:
A key long-term research goal within our laboratory is development of "surgical assistant" systems creating a three-way partnership between human surgeons, technology (robots, sensors, etc.) and information to improve patient care. Within this framework, we wish to develop modes of "shared autonomy" in which a surgical robot can actively assist in executing surgical maneuvers. To do this, both the surgeon and the computer controlling the system must have a shared understanding of the surgical task, patient anatomy, and the progress of the surgery. Our strategy for implementing this complementary situational awareness rests heavily on developing and maintaining real-time "digital twin" simulation models of the patient and surgical procedure, in which actions of the robot and sensed information from computer vision and other sensors is used to update the model. Similarly, the simulation model can be used to help the controller to interpret and execute surgeon commands to the system. Currently, we have initial implementations for key components of this architecture, but fully implementing our vision will involve multiple research projects.

Possible projects include:

- Real-time computer vision to recognize and update models of patient anatomy and tool-to-tissue interactions
- Online updating of robot-to-model and model-to-patient registration
- Augmented reality display of relevant information from the simulation model to

the surgeon
- Improvements to the underlying simulation framework
- User studies involving surgeons with an existing robot and physical phantoms

Required Skills:
Specific skills will depend on the project chosen. Experience in C/C++ programming is important. Many of the specific projects will require computer vision, computer graphics, or experience with simulation systems. Similarly, experience in statistical methods for reducing experimental data would be very desirable for user studies.

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

9. 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.

10. <u>Development of a sensorized amphibious fish robot for force feedback control to traverse mud of varying strength</u>

PI: Chen Li
Mentor: Divya Ramesh

Project Description: Amphibious fishes regularly make forays onto land using three distinct strategies. We used three model organisms to study traversal on mud of different strength. Here we studied the mudskipper, bichir and ropefish for appendicular, axial-appendicular and axial locomotion respectively. All the three species had more sinkage and body contact with mud during locomotion as the mud weakened. The mudskipper's distance over each cycle reduced as the mud weakened and it compensated by using its tail to propel forward. The other two species lifted some body sections likely to reduce drag. We have developed a feedforward-controlled robot physical model to better understand our observations.

Combining our animal observations and the preliminary robot results, our next step is to build a sensorized robot. This robot will use force as feedback to detect changes in mud strength and vary its mode of locomotion based on the mud strength as feedback control.

Please see the talks for more details on our recent <u>animal</u> and <u>robot</u> work.

Role of REU Student: The REU student will build a prototype of the sensorized robot and develop feedback control strategy for the robot based on animal and previous robot results. The student will then perform preliminary experiments to show the robot's performance on mud with different strengths.

Required Background & Skills: Strong CAD design skills, including mechatronics, 3D printing, machining, microcontroller programming, servo motors/linear actuators, MATLAB and willingness and comfort to handle and care for vertebrate animals

Preferred Background & Skills: Feedback control, circuit design, signal processing

11. <u>Autonomous Robotic Surgery</u>

PI: Axel Krieger
Mentor: Jiawei Ge

Project Description: Autonomous robotic surgery systems have the potential to significantly improve efficiency, safety, and consistency over current tele-operated robotically assisted surgery (RAS) with systems such as the da Vinci robot (Intuitive Surgical). Elastic and plastic deformations occur constantly during soft tissue surgeries such as suturing and tumor resections. Accurately predicting tool and tissue deformations and compensating for them in surgical plans is paramount for accurately performing robotic surgeries and interventions. In this project, we will explore model and data-driven approaches to predict in real-time deformations and adjust surgical plans for suturing and tumor resections. The proposed research on deformation prediction will produce methodologies for understanding tissue behavior and how to compensate for deformations.

Role of REU Student: The REU student will help develop model based and model-free estimations of tissue deformations using finite element modeling (FEM) and data driven models based on experimentations. these innovations will provide the predictive accuracy necessary for precision surgery that cannot be achieved by either the biomechanical model or model-free methods in isolation.

Required Background & Skills: Required skills include:

- Basic or better object-oriented programming skills
- Familiarity with computer aided design and FEM
- Experience with conducting experiments

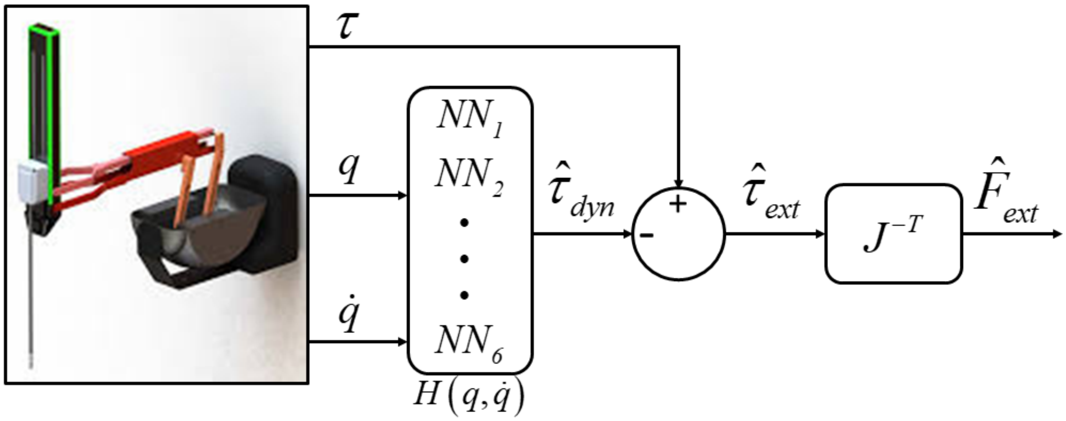
Preferred Background & Skills:

- Understanding of biomechanics for tissue interactions
- Robotics experience
- Experience with robot operating software (ROS)

12. <u>Learning-based Force Estimation for Robotic Surgery</u>

PI: Peter Kazanzides

The lack of haptic feedback has been cited as a limitation of the da Vinci surgical system. Surgeons have adapted by relying on visual cues to estimate interaction forces, but haptic feedback could improve surgeon performance, especially for novices. We have previously demonstrated that neural networks can be used to estimate internal joint torques (e.g., due to dynamics), based on the measured joint positions and velocities, and that external forces can be estimated by subtracting these internal joint torques from the measured joint torques (based on measured motor currents). Our experimental results, on the da Vinci Research Kit (dVRK), have shown that the neural network can estimate internal joint torques with a relative RMS error of about 10% (typical) and up to 20% in some cases. The accuracy of Cartesian force estimation is typically about 1N. There are, however, cases where the performance is worse. The goal of this project is to improve the accuracy and robustness of external force estimation by improving the methods and by leveraging recent dVRK controller enhancements, and to also investigate the performance of this method on the next generation of dVRK hardware, specifically the patient side manipulator (PSM) from the da Vinci S and Si.



13. Optimal Magnetic Resonance Imaging Parameters for AI Models

PI: Jerry L Prince

Mentor: Savannah Hays

Project Description: The performance of deep learning algorithms in medical image analysis is often hindered by the phenomena of *domain shift* when the testing data does not come from the same distribution as the training data. Magnetic resonance images (MRIs) are acquired with a variety of imaging parameters in the clinical setting due to its lack of standardization. We take advantage of artificial intelligence (AI) algorithms for quick, reliable, and consistent analysis, but it is unknown if we are achieving optimal performance. This project will focus on exploring the optimal imaging parameters for state-of-the-art pretrained AI models used in medical image analysis.

Role of REU Student: The REU student will run various AI models used in medical image analysis on a variety of different brain MRIs. Based on the resulting data, the REU student will conclude the impact of imaging acquisition parameters on the performance of the AI models using statistics and visualization.

Required Background & Skills: Python

Preferred Background & Skills: Basic image processing and prior exposure to deep learning.

14. Super-Resolution of Anisotropic Magnetic Resonance Images

PI: Jerry L Prince

Mentor: Samuel Remedios

Project Description: Clinical magnetic resonance imaging (MRI) produces 3D volumes that are often acquired as stacks of 2D slices. The thicknesses of these slices may vary depending on the physician's needs and/or preferences. However, thicker slices result in lower through-plane resolution, which hampers results of automated image processing algorithms. We have developed several super-resolution (SR) algorithms which aim to improve the resolution of such "anisotropic" magnetic resonance volumes. The goal of this project is to compare our SR algorithms against others, analyze results, and potentially propose a novel algorithm if needed.

Role of REU Student: The REU student will run various super-resolution algorithms on publicly available MRI datasets. The student will analyze results and report findings, as well as propose potential solutions to any drawbacks found in the existing algorithms.

Required Background & Skills: Python

Preferred Background & Skills: Image processing experience, prior exposure to deep learning

15. Optical coherence tomography (OCT) for longitudinal retinal thickness analysis

PI: Jerry L Prince

Mentor: Shuwen Wei

Project Description: Optical coherence tomography (OCT) is a non-invasive imaging modality, routinely used to measure retinal thickness via a low-coherence laser source to generate volumetric retinal images at micro-scale resolution. Multiple sclerosis (MS) is a neurological disease that affects the thickness of certain retinal layers. This project aims to explore the longitudinal trend of retinal thickness in people with MS and analyze the various factors that may affect retinal thickness.

Role of REU Student: The REU student will conduct statistical analysis on the longitudinal retinal thickness data, perform analyses, and derive conclusions.

Required Background & Skills: Python

Preferred Background & Skills: Statistical analysis

16. Enhancing Usability of Diffusion-Weighted MRI Acquired with Limited Directions

PI: Jerry L Prince

Mentor: Zhangxing Bian

Project Description: Diffusion-weighted imaging (DWI) is a powerful MRI technique that can provide valuable information about the microscopic structure of tissues, particularly in the brain. However, acquiring DWI with a comprehensive set of diffusion directions can be time-consuming and challenging, particularly in clinical settings where the resources and time with patients is limited. Consequently, images are often acquired with fewer directions, leading to lower angular resolution and higher noise levels that can impair diagnostic accuracy. This project aims to address these limitations by developing machine learning-based image processing algorithms. Enhancing the quality and usability of these images will facilitate faster and more accurate diagnoses.

Role of REU Student: The REU student will investigate innovative solutions to improve the signal-to-noise ratio and angular resolution of DWI images. By implementing and testing cutting-edge denoising and super-resolution techniques, the student will contribute to democratize high-quality DWI analysis.

Required Background & Skills: Solid programming skills in Python, familiarity in signals & systems, and deep learning.

Preferred Background & Skills: Knowledge of MRI physics and prior experience with image processing and medical imaging data is beneficial.

17. Refinement of deep learning based multiple sclerosis lesion segmentation using classic iterative methods.

PI: Jerry L Prince

Mentor: Jinwei Zhang

Project Description: State-of-the-art lesion segmentation algorithms have been achieved by deep learning (DL) methods, including multiple sclerosis lesions. However, upon examining individual lesion masks generated by DL methods, there are instances where unsatisfactory lesion boundary delineations are observed. In such cases, a post-processing step applied to the lesion masks generated by DL is expected to refine and produce more accurate lesion masks.

Role of REU Student: The student will implement various classic iterative lesion segmentation methods by growing and refining DL-identified lesions around neighboring voxels. The student will further validate the implemented algorithms using a cohort of patient datasets.

Required Background & Skills: Python

Preferred Background & Skills: Basic image processing, exposure to deep learning

18. <u>Digital EEG Marker for Epilepsy and other Mental Health Disorders</u>
<u>PI Sarma</u>

According to the WHO, an estimated 5 million people worldwide receive a diagnosis of epilepsy annually.

Unfortunately, misdiagnosis rates range between 20% to 42%. A false positive leads to inappropriate treatment with unnecessary antiseizure medication with potential adverse reactions, failure to receive suitable therapy for the correct diagnosis, and unnecessary restrictions that arise with the stigma of epilepsy. A false negative comes with increased risks of seizure recurrence, status epilepticus, and premature death. The diagnosis of epilepsy depends on a comprehensive clinical history, neurological examination, and ancillary studies including scalp electroencephalography (EEG). Scalp EEG can confirm an epilepsy diagnosis if
abnormalities indicating epilepsy, such as random interictal (between seizure) epileptiform discharges (IEDs) or focal slow wave activity, are present and detected by visual inspection. However, the sensitivity of abnormalities being present in the EEG varies from 29-55%, and the ability for clinicians or EEG technicians to detect them by visual inspection varies. EEG artifacts can both mask IEDs and be mistaken for IEDs. Consequently, it takes multiple visits, months, or even years to be accurately diagnosed. This project involves building an EEG marker for epilepsy that is independent of abnormalities being present in the EEG. Rather, we aim to uncover hidden network properties that only exist in epilepsy and no other condition by building dynamic network models (DNMs) from the EEG data. This approach can be applied to several
neurological disorders where brain network dynamics

<u>19. MOSSAIC: Multimodal On-body Sensor Array for Analysis of Internal</u> **Cognitive Correlates:** Bedside monitoring is routinely used to enhance

the quality and safety of care in hospitalized patients. With a focus on non-invasive and contact-less measurement methods, clinicians have been able to access critical physiological characteristics of patients more quickly upon hospitalization and for longer periods of time. For example, non-invasive pulse oximetry monitoring, which became a standard in the patient care paradigm in the 1980s, has lowered retinopathy of prematurity (malformation of the eye) by as much 58% in severely underweight newborns. Other advancements such as piezoelectric bed inserts providing continuous heart and respiratory rates have been shown to increase early detection of respiratory failure and reduce cardiac arrests by 86% as compared to beds without these measurement capabilities. Our MOSSAIC sensor suite and assessment software aim to continue the development of bedside, and home technologies to predict impending decompensation in patients' health or to track their recovery trajectory.

REU students will participate in the IRB approved assessment of both healthy and infirmed patients. They will assess the effectiveness of the MOSSAIC sensors and help develop AI-enhanced algorithms to characterize the health of the users. *Faculty Advisors: Professor Ralph Etienne-Cummings and Dr. Robert Stevens*