List of Potential REU Projects for Summer 2019

Electrical and Computer Engineering Dept., Montana State University

Understanding neuronal cell communication through light

Mentor: Prof. Anja Kunze (1 Student Summer 2019)

Brain cell communication relies on receiving and sending currents through neural networks due to concentration differences in sodium, potassium, or calcium ions. To better understand how dynamic changes within neuronal networks impacts the communication from cell to cell, we developed an imaging platform allowing us to monitor electrical and fluorescent calcium signals simultaneously. Employing microelectrode arrays and calcium fluorometry we can stimulate and track network activity across several millimeters at a single cell resolution. The REU student will have the opportunity to learn how to grow brain cells derived from the rodent cerebral cortex on microelectrode arrays, how to record optical and electrical signals from brain cell cultures and how fluorescently emitted light travels through a grown neuronal network. Furthermore, depending on the student's interest and background she/he can either induce changes within the neuronal network through magnetic forces, magnetic field gradients, or electrical stimulation and study resulting communication pattern. Overall this project will expose the student to current challenges in understanding brain cell function, current limitations of light-based and electrode-based methods to analyses neuronal cell behavior and current challenges of big data signal processing. At the end of the summer, the student will be expected to write a four to six-page IEEE paper to be presented at an international IEEE brain-related conference.

Volcanoes on Venus: Automatic Detection in Radar Images

Mentor: Prof. Brad Whitaker (2 students summer 2019)

Modern spacecraft detect and record amazing information that is analyzed by scientists on earth. These measurements have deepened our understanding of the universe and allow us to monitor terrestrial and extraterrestrial events. However, measurement devices deployed in space currently make many more measurements than they are able to send back to Earth. This communication bottleneck implies that only a subset of the data can be analyzed on the ground. The purpose of this project is to develop an algorithm that can autonomously determine which measurements are most interesting and should therefore be sent to Earth. Specifically, we will analyze a set of radar images of the surface of the planet Venus with the goal of automatically detecting the presence of volcanoes in an image. Techniques developed during this project can be extended to other measurement devices in order to improve the quality of information that gets sent back to Earth.

Acoustical monitoring of parks, wilderness, and other natural areas in Montana

Mentor: Prof. Rob Maher (1-2 students summer 2019)

According to current U.S. National Park Service (NPS) management policies, the natural soundscape of parks and historic sites is a protected resource just like the physical ecosystems, landscapes, and historic artifacts for which the parks were formed. While several NPS sites have been studied extensively for noise intrusions by tour aircraft and mechanized recreation, most parks and historic sites do not yet have an acoustic baseline for management purposes. Moreover, very little is known in a scientific sense about the diurnal and seasonal variations in natural sound, nor about the long-term trends in the natural soundscape. Understanding ecosystems and the role of human activity in the natural world benefits from observing natural acoustics of animal communication, environmental sound from wind, rain, and flowing water, and anthropogenic sound sources. Ongoing research at Montana State University involves long-term acoustical monitoring research at remote locations. Students participating in this research will gain a theoretical and practical understanding of environmental acoustics (the propagation, reflection, absorption, and attenuation of sound in the atmosphere), experience designing and conducting field research, scientific interpretation and documentation of acoustical recordings, and the development of new means for automated acoustical processing and analysis.

Nanofabrication of optical devices

Mentor: Prof. Wataru Nakagawa (1-2 student summer 2019)

Micro- and nano-fabrication technologies based on silicon have enabled a vast range of technological advances, including microprocessors, integrated systems, and optoelectronics. The Nano Optics group uses these manufacturing technologies to produce functional optical devices based on nanostructures in silicon and related materials, optimized for applications in polarimetry and optical imaging. The participating student will be given an introduction to these fabrication technologies and hands-on training in working in a clean room facility. Working with group members, the REU student will be assigned a sequence of steps in the fabrication process chain to understand and optimize, and to assist in fabricating functional optical devices in our facility.

Optical metamaterial characterization

Mentor: Prof. Wataru Nakagawa (1-2 student summer 2019)

The Nano Optics group is developing and testing composite optical materials (metamaterials) with engineered polarization properties for sensing and other applications. The optical properties including polarization characteristics of these devices must be thoroughly measured and analyzed in order to understand their performance and give feedback to the design and manufacturing processes. This involves using an optical characterization system to measure the spectral and polarization properties of the metamaterials under test, including laboratory automation and signal processing/analysis tools. The REU student will be trained on the operation of this system, assist in its calibration and testing, perform measurements on fabricated metamaterial devices, and potentially assist in making improvements to the system.

Drone-based imaging experiments

Mentor Prof. Joseph Shaw (2 students summer 2019)

In this project, two students will work with graduate students and faculty to fly drones carrying hyperspectral, thermal, and RGB imagers in field experiments to study river ecology. The students will assist with field experiments and with calibrating and processing the images using

Matlab and Python programming languages. The students also will perform optical calibration measurements in the lab. Students on this project should be interested in optics and imaging.

Machine learning of sensor data

Mentor: Prof. Ross Snider (1 student summer 2019)

REU students will learn to answer the questions, ‘once you have detected, observed, and measured natural phenomena, what do you do with the data you have collected?’ and ‘how do you make sense of the data by classifying it?’ Students will learn how to apply state-of-the-art machine learning algorithms, such as Support Vector Machines (SVM) on multidimensional data. One possible application of this method is to analyze the output data from optical sensing systems, such as deformable optical waveguide sensors, which may provide a high number of information channels, but in a convolved and noisy form. Advanced signal processing is required to analyze these output signals, and extract the measurement parameters of interest. Students also will learn how to implement these algorithms and visualize data in MATLAB, the primary language and interactive environment used by engineers and scientists worldwide.

Active optical devices and systems

Mentor: Prof. David Dickensheets (1-2 students summer 2019)

Prof. Dickensheets’ group is developing active optical devices for advanced imaging applications. One example is tunable reflective lenses (variable curvature mirrors) with fast and precise control over focal power and spherical aberration. These mirrors are useful for laser scanning systems such as confocal or two-photon microscopes, and also for fast-response zoom lenses for small format cameras. In addition to device engineering, Dickensheets’ group is building complete optical instruments such as a miniaturized microscope for skin cancer detection, and a full-sized two-photon fluorescence microscope with advanced active and adaptive optics to facilitate research in developmental biology. These instrument development efforts are inherently interdisciplinary, and REU students engaged on these projects will work side by side with graduate and undergraduate students pursuing degrees in engineering, cell biology, neuroscience and physics. Depending on student interest, the REU student will be afforded the opportunity to learn microfabrication processing techniques in the Montana Nanotechnology Facility, optical characterization and metrology techniques applicable to micro-mirrors and active optical systems, or optical system control, modeling and software development. Importantly the student will learn tangible research skills while simultaneously learning about the cross-disciplinary applications and challenges these projects address.

Light and nanotechnology

Mentors: Prof. David Dickensheets, Prof. Recep Avci, Mr. Chris Arrasmith (1-2 students summer 2019)

Several projects are available for students interested in learning about applications of nano/microfabrication to optical systems, and vice versa. We are developing light-based metrology tools to measure film stress, and new coating methods to make high-reflectivity optical mirrors, especially on flexible substrates. Other projects will advance our capabilities for assembly and packaging of optical MEMS devices so that they can be deployed in instruments outside the cleanroom laboratory. Finally, MSU is home to some of the most advanced thin films characterization and imaging instruments available today, and opportunities exist to learn advanced SEM and Auger spectroscopy techniques. Students interested in these applications will receive training to work in the Montana Nanotechnology Facility (MNF), which is part of a national network of such facilities called the National Nanotechnology Coordinated Infrastructure (NNCI). With additional support from NSF through NNCI, our Nanotechnology students will have the opportunity to visit one of the other NNCI sites and interact with REU students from around the nation doing research related to nanotechnology.

Satellite networks using free-space optical communications

Dr. John Roudas (1 student summer 2019)

The proliferation of Low-Earth-Orbit (LEO) small satellites in the years to come offers new opportunities for space communications. Large constellations of such satellites will be required to offer constant 100% global coverage for earth environmental monitoring. Current LEO constellations use radio frequency (RF) links to communicate with ground stations and user terminals. However, since there will be a very large number of these satellites with a very restricted power budget for communications, it is anticipated that it will be impractical to have individual satellites communicate directly to Earth using point-to-point links. It will be much more cost efficient to organize clusters of LEO satellites in a hierarchical satellite network. In this scenario, LEO satellites within a cluster will communicate using low-cost, low-power, low-data-rate transceivers with dedicated communications satellites acting as relays. These communications satellites will be the hubs of an optical backbone satellite network (an equivalent to the fiber-optic backbone network interconnecting central offices on Earth). They will collect and store data, multiplex them into larger data streams, and periodically transmit these data streams to Earth, when weather conditions are favorable, through high-capacity optical links. The latter can be implemented using free-space optical communications systems based on wavelength-division multiplexing (WDM), initially employing direct-detection and eventually digital coherent receivers. This project proposes to study the design of point-to-point WDM optical communications systems between the Earth and communication satellites. In this context, we will first improve the spectral efficiency of NASA's Laser Communications Relay Demonstration (LCRD) transceivers currently using binary differential phase shift keying (BDPSK). This can be accomplished by transitioning to higher-order DPSK and multiple symbol detection. As a further step, we will study, by modeling and simulation, the advantages and disadvantages of using next-generation coherent optical communications systems for space communications.