Session N Abstracts

Channel Selection for Feature-Extracted Data From Microelectrode Array Brain-Machine Interfaces

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Mentors: Azita Emami and Benyamin Haghi

Implantable microelectrode arrays are a type of brain-machine interface consisting of hundreds of electrodes, each transmitting a channel of neural data to be decoded into instructions. The quality of data varies between channels, and changes over time. Currently, we are feeding all channels to our decoder, but this approach is inefficient. Channel selection could enable the elimination of all but the top channels, improving the efficiency of decoding without sacrificing accuracy. In this project, we explored different architectures for channel selection algorithms. We developed binary good/bad classifiers for post-feature-extraction neural data, based on set-length segments of feature-extracted data from individual channels, which are labeled “good” or “bad” depending on the performance of a linear decoder trained on just those channels. We compared the effectiveness of several high-performing algorithm designs, including: gradient boosting, support vector machines with linear and RBF kernels, and fully connected networks. Currently, we have achieved an accuracy of 81% overall and 60% for good channels only. We will continue to evaluate more algorithms, and explore methods of improving performance, with the goal of designing a robust, accurate channel selector which proves effective on future days and with new patients.

Assessment of Electrochemical Sensors Sensitivity for Integration in Chronic Wound Management Device

Alex Seder
Mentor: Wei Gao

Increasing instances of chronic wounds have become a significant concern, particularly in cases of cancers, heart conditions, diabetes, and autoimmune disorders, necessitating specialized care and extended healing periods. In this study, we focus on enhancing wound monitoring through the application of previously established electrochemical sensors within the Gao lab's Smart Bandage device. Our objective is to enable noninvasive tracking of wound physiological conditions, including pH, hydrogen peroxide, oxygen, nitric oxide, and temperature. Testing of pH, hydrogen peroxide, and nitric oxide sensors was conducted following standard protocols, with sensitivity and stability consistently maintained within a range of 5-10% for all tested sensors.

Our findings revealed that hydrogen peroxide stability is compromised outside the pH range of 7 due to the instability of the Prussian Blue. Nitric oxide sensors demonstrated robustness across different pH levels, displaying enhanced sensitivity and voltage at lower pH values, and reduced sensitivity with lower voltage at higher pH values. Through systematic assessment of our sensors under varying pH and temperature conditions, we effectively determined the bandage's capabilities in assessing diverse pH and temperature scenarios. Looking ahead, the integration of electrophysiological therapeutic treatment into the bandage holds promise for stimulating tissue regeneration. Furthermore, the potential utilization of solar cells or magnetoelastic generators for powering such therapeutic measures introduces the possibility of a self-sufficient and comprehensive monitoring system tailored for chronic wounds.

Machine Learning Model to Predict Patient Fatigue Using Data From Wearable Sensors

Ashwitha Surabhi
Mentors: Wei Gao and Changhao Xu

Wearable sensors have become an increasingly popular area of research due to their ability to transform the medical industry by allowing the measurement of a patient’s physiological signals in constant time. In this project, we are measuring the pulse, GSR (Galvanic Skin Response), and temperature data from patients and using this data to predict patient fatigue, which becomes important for a patient as they are able to monitor their own health and energy levels throughout the day. Using data processing techniques, we are able to analyze the raw data from the patient and create more metrics such as systolic upstroke velocity time for pulse data and weighted moving average data for temperature and GSR data. Then, using machine learning techniques, specifically a transformer model using GPT 2, we will be able to take this data from the wearable sensor as an input to predict patient fatigue levels.

Investigation, Modeling, and Control of Quantum Optoelectronic Circuits and Systems

Pablo Backer-Peral
Mentors: Ali Hajimiri and Volkan Gurses

Optoelectronic circuits leverage the advantages of both photonics and electronics to enhance the performance of sensing, communications, and computing systems. Quantum photonics is an emerging field that leverages the quantum mechanical nature of light to create systems beyond the limit of classical photonics. Quantum optoelectronic circuits expand the scope of quantum photonics by enabling a holistic integration of quantum photonic and electronic functions, offloading some of the functional requirements from optical circuits to radiofrequency circuits. To this end, this project aims to develop quantum optoelectronic circuits and their control systems to demonstrate novel functionalities and improved performance. Some of the contributions of this work will be, but are not limited to, building prototype and printed circuit boards for quantum optoelectronic circuits, developing scripts to automate the readout and control of the experiments, and programming FPGAs for real-time processing of measured quantum signals.

Development of a Coherent Optical Receiver for Fiber Optic Communication Applications

Olivers Prānis

Mentors: Ali Hajimiri and Samir Nooshabadi

Fiber optic technology has already proven to be a vital part of the modern world. Whether it is establishing a high-speed Internet connection for a single household or entire countries, using light to transmit information is currently the fastest way to communicate across short and long distances. However, with the increasing demands for ever faster speeds and higher bandwidths, there is a need for improved designs for optical receiver systems to translate the optical signals into electronic ones. This research project focuses on developing and characterizing a new type of integrated optical receiver utilizing coherently modulated light waves.

Realizing Photonic Integrated Circuits on Thin Film Lithium Niobate

Parthorn Ammawat

Mentors: Alireza Marandi and Ryoto Sekine

Integrated photonics based on thin film lithium niobate (TFLN) has been a promising all-optical solution for low-cost and energy-efficient communication, sensing, and computing. Due to its strong nonlinearity, TFLN has emerged as a promising foundation for modern systems including photonic computing. However, all computers require a combination of linear and nonlinear operations. While these elements have been demonstrated individually on TFLN, they have yet to be combined on the same chip to implement a full computer. To do so requires further optimization of both components to make them compatible with each other. One vital component of the circuits is optical couplers. This project optimized several types of couplers and performed fabrication sensitivity tests on them. These were done by using commercial software, then the results were verified by using different simulation methods, including MODE, EME, and FDTD. The real devices were then fabricated, and the results were measured.

Experimental Feasibility of Photon Blockade With Weakly Nonlinear Kinetic Inductance Resonator

Daniil Zhitov

Mentors: Mohammad Mirhosseini and Chaitali Joshi

A theoretically proposed protocol for producing photon blockade in weakly nonlinear systems is studied. Feasibility of its experimental implementation using a kinetic inductance resonator with fourth-order nonlinearity is analyzed in relation to limitations of nonlinearity, one- and two-photon drive strengths. Parameter optimization is discussed. The analysis was conducted using numerical simulations and theoretical tools. The protocol is found to be possible, but challenging, to implement. There is potential for producing highly non-classical non-Gaussian and Wigner negative states, that could be a valuable resource for quantum technology. Further work includes attempting to implement the protocol 'on-chip' and verifying its performance with quantum state tomography.

Characterization of Thin-Film $BaTiO_3$ Using Surface Acoustic Waves

Nuha Akhtar

Mentors: Mohammad Mirhosseini and Hao Tian

With the ability to be confined close to the surface, coherently excited and detected with microwave electronics, stored in compact high-quality resonators, and have their properties engineered by choice of material, Surface Acoustic Waves (SAWs) have become the ideal candidate for studying quantum behavior of macroscopic objects. Using piezoelectric materials, which have a unique property of electromechanical coupling, acoustic devices can be used in the quantum regime. Since functionality of a piezoelectric crystal is based on its physical parameters, this property-dependent performance acts as motivation in the search to find materials that will accomplish the task of sensing and actuating SAWs. Having many excellent physical properties, Barium Titanate (BTO) has become the piezoelectric crystal of interest in this lab. With a limited amount of thin-film nanofabrication and analysis of material properties reported, we aim to establish a parameter space that maximizes the effect of BTO's piezoelectric response through finite element analysis and material characterization. In the future, this information will allow for the fabrication of a successful SAW device that can be used to characterize BTO for a variety of quantum applications at the cryogenic level.

SQUID Noise Spectroscopy: Designing Superconducting Qubits for Environmental Flux Noise Measurement

Alexander Deters

Mentors: Oskar Painter, Andreas Butler, and Gihwan Kim

Superconducting quantum interferometry devices (SQUIDs) have long been used for designing superconducting qubits with flux dependence. While primarily employed for in situ parameter tuning, these components have also been shown to make superconducting circuits effective tools for flux noise spectroscopy. This project aims to design an experimental setup wherein several tunable qubits, each with distinct SQUID geometries, are used to achieve accurate measurements of the environmental flux noise—distinct from local noise sources such as fabrication defects and atomic spins. To this end, we produce a fabricatable design for an eight-qubit quantum computer optimized for this measurement. Additionally, we introduce PySon, a Python library capable of automating design processes in the electromagnetic simulation software Sonnet. PySon's automation of design, simulation, and post-processing tasks enables the creation of a physically informed procedural generator for metamaterial Purcell filters. This generator is then applied to mitigate extraneous noise in our design.

Design of a Qubit Module for High Fidelity State Transfer From Quantum Transducers

Ricky Parada

Mentors: Oskar Painter and Piero Chiappina

The transmission of information between remote nodes in a quantum network would expedite prospects such as quantum cryptography and distributed quantum computing. Due to their dominance in control and operating times, superconducting quantum circuits (SQCs) are primary candidates for realizing scalable quantum computers. However, cryogenic temperature dependencies render SQCs incompatible with long-range transmission. To overcome this issue, quantum transducers are being developed to convert microwave photons into optical photons better suited for network communication via optical fibers. Going forward, it is crucial to design a qubit module that can efficiently catch photons emitted from these transducers. We design an SQC module that facilitates efficient quantum information transfer from a transducer to a superconducting qubit using a directional photon catch scheme. We calculate the optimal temporal pulse shape of transducer-emitted flying photons through detailed state transfer simulations and determine the corresponding qubit parameters that emit such a pulse. We achieve an effective qubit-photon coupling rate of ~12 MHz as a result of optimizing the transducer to qubit fidelity subject to the numerous theoretical and physical constraints. Future work includes implementing the design on a standard qubit layout to experimentally realize quantum state transfer and remote entanglement mediated by quantum transducers.