UCLA Samueli
School of Engineering

Summer Undergraduate Research Program at the Engineering Student Resource Center
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UCLA Samueli School of Engineering
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UCLA Samueli
School of Engineering

SUMMER
UNDERGRADUATE
RESEARCH PROGRAM

2019

RESEARCH JOURNAL

Table of Contents

Student Research Abstracts & Posters

Poster Symposium and Awards Ceremony | August 16, 2019

First Floor Engineering VI: Mong Auditorium, Lobby and Patio

11:00 AM - 11:05 AM Announcement (William Herrera)

11:05 AM - 12:30 PM Poster Galley Walk

11:45 AM - 12:30 PM Hors d'oeuvres service begins

12:30 PM - 2:00 PM Awards Ceremony

DEAN'S MESSAGE

The Summer Undergraduate Research Program (SURP) provides participants with an intensive 8-week summer research experience in a wide range of engineering fields. Undergraduate students participate in research with UCLA Samueli School of Engineering faculty and research teams to gain real-world lab experience. As part of this program, SURP students:

- Meet and network with peers who have similar goals and interests
- Learn to communicate research outcomes by participating in weekly Technical Presentation Labs
- Create a professional scientific poster of their research
- Write and publish a research abstract
- Present a detailed Summary of Project
- Become more competitive when applying to engineering graduate schools

This year, 39 undergraduate students were selected to join the 2019 SURP cohort. I would like to congratulate this SURP class on completion of their amazing research projects. Creating new knowledge is a very important, and a very difficult, task. These high-performing students have done an outstanding job working through the rigors and challenges of full time research. They should be very proud of the abstracts and posters they have published today. I encourage you to meet the students, ask questions about their projects, and learn about the cutting-edge knowledge that is being created here at the UCLA Samueli School of Engineering.

Sincerely,

Jayathi Murthy
Ronald and Valerie Sugar Dean

LAB NAME

Signal Processing and Circuit Engineering Laboratory

FACULTY ADVISOR

Professor Sudhakar Pamarti

GRADUATE STUDENT DAILY LAB SUPERVISOR

Shi Bu

DEPARTMENT

Electrical and Computer Engineering

Neha Adhlakha

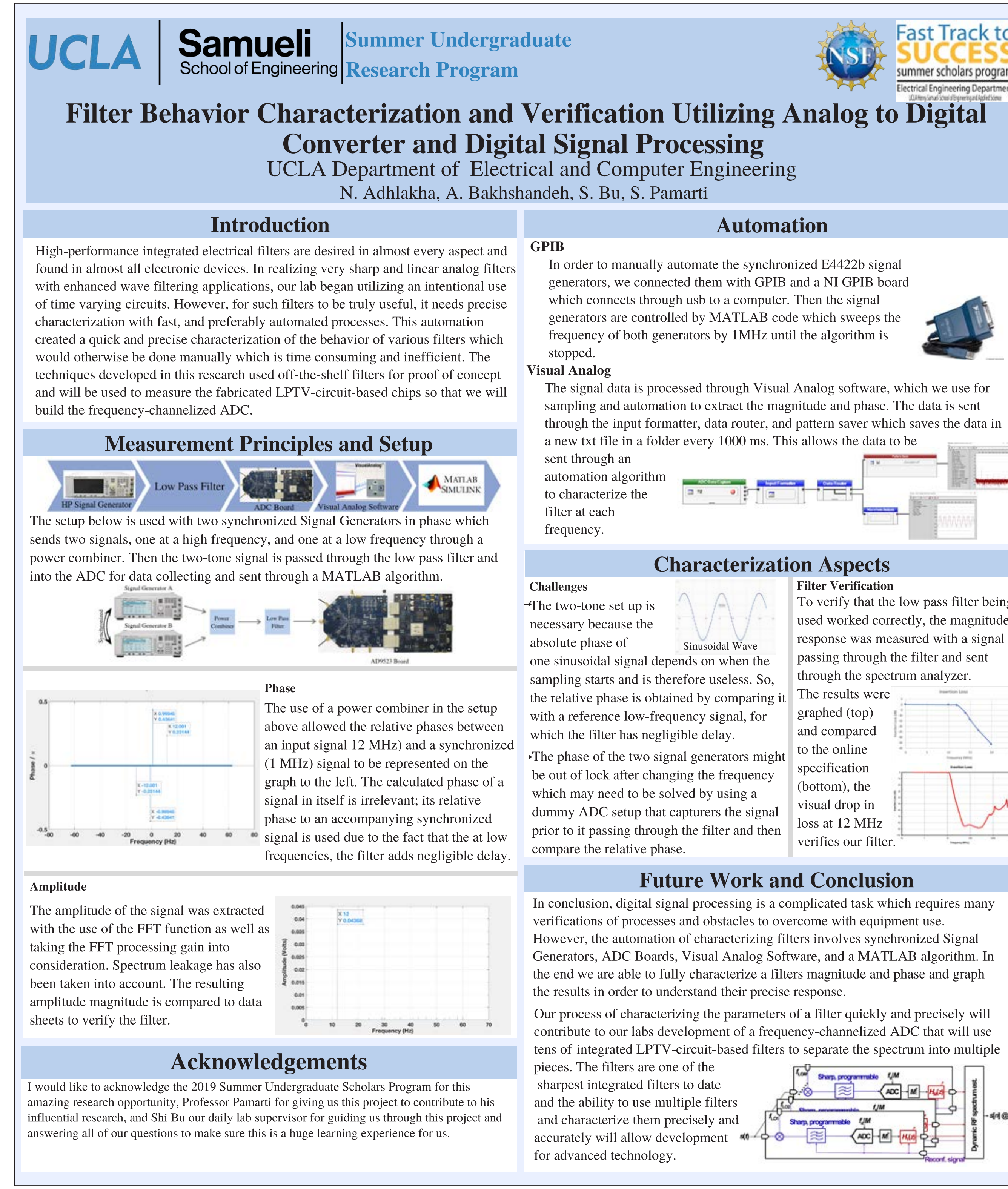
Electrical Engineering

Second Year

UCLA

Filter Behavior Characterization and Verification Utilizing Analog to Digital Converter and Digital Signal Processing

High-performance integrated electrical filters are desired in almost every aspect and found in almost all electronic devices. In realizing very sharp and linear analog filters with enhanced wave filtering applications, our lab began utilizing an intentional use of time varying circuits. However, for such filters to be truly useful, it needs precise characterization with fast, and preferably automated processes. Developing this automation involved signal generators and an analog-to-digital converter to create a quick and precise characterization of the behavior of various filters which would otherwise be done manually which is time consuming and inefficient. The ADC board combined with two synchronized signal generators allows the signal to be sent to a MATLAB algorithm and hence obtain the desired magnitude and phase responses of the filter. The signal generation and process is more complex than sweeping the input frequency because the automation produces many challenges including equipment noise. My research aims to overcome these obstacles with digital signal processing. Our process of characterizing the parameters of a filter quickly and precisely will contribute to our labs development of a frequency-channelized ADC that will use tens of such filters to separate the spectrum into multiple pieces.



LAB NAME

Terahertz Devices and Intersubband Nanostructures Group Laboratory

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Parastou Mortazavian

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Nathan Atkinson
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Diamond as an output coupler for chip-scale terahertz external cavity quantum cascade lasers

External cavity quantum cascade lasers are an integral source of terahertz radiation. However, heat removal from the devices is critical in order to achieve continuous wave operation. We introduce a chip-scale output coupler for a quantum cascade vertical external-cavity surface emitting laser (QC-VECSEL) through a 500 um thick synthetic polycrystalline diamond plate. This design brings two primary benefits: a method of dissipating heat from the laser's bias region and a mechanically stable output coupler with no need for alignment. The diamond is mounted directly on top of the metasurface, replacing an existing design involving an externally mounted quartz output coupler. Initial electromagnetic simulations indicate acceptably high reflectance at a resonant lasing frequency of 3.4 THz and a bandwidth of about 140 GHz. Thermal simulations will be conducted to predict the expected improvements to operating temperature and heat dissipation for the VECSEL's metasurface. Possible areas of concern include high threshold current and increased thermal losses due to an adjusted ridge geometry that features a high fill factor.

Diamond as a chip-scale output coupler for terahertz quantum cascade lasers

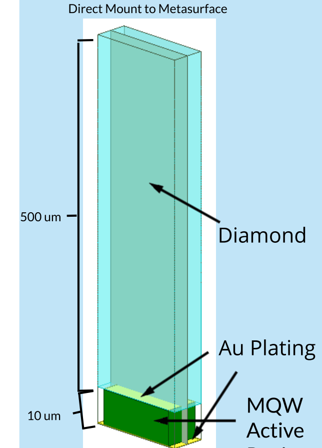
Nathan Atkinson, Parastou Mortazavian, Christopher Curwen, and Benjamin Williams
Department of Electrical and Computer Engineering, University of California, Los Angeles

Abstract

External cavity quantum cascade lasers are an integral source of terahertz radiation. However, heat removal from the devices is critical in order to achieve continuous wave operation. We introduce a chip-scale output coupler for a quantum cascade vertical external-cavity surface emitting laser (QC-VECSEL) through a 500 um thick synthetic polycrystalline diamond plate. This design brings two primary benefits: a method of dissipating heat from the laser's bias region and a mechanically stable output coupler with no need for alignment. The diamond is mounted directly on top of the metasurface, replacing an existing design involving an externally mounted quartz output coupler. Initial electromagnetic simulations indicate acceptably high reflectance at a resonant lasing frequency of 3.4 THz and a bandwidth of about 140 GHz. Thermal simulations will be conducted to predict the expected improvements to operating temperature and heat dissipation for the VECSEL's metasurface. Possible areas of concern include high threshold current and increased thermal losses due to an adjusted ridge geometry that features a high fill factor.

VECSEL Coupled with Diamond

Direct Mount to Metasurface

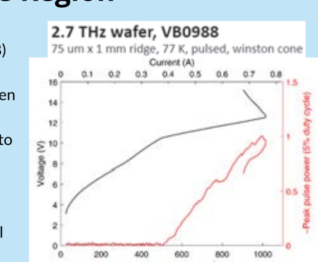


Diamond is a superb thermal conductor and a strong electrical insulator. Consequently, it serves as a viable output coupler and heat spreader for the metasurface. Placing diamond on top of the metasurface serves to remove the external cavity and create a pseudo-monolithic system which may offer improved mechanical stability in applied settings. The diamond introduces a lossy medium through which the laser beam must travel. Carbon vapor deposition (CVD) diamond has been observed to have an optical refractive index of about 2.378.[2] This changes the beam's resonant frequency; the ridge geometry must be adjusted to realign the resonance with the target 3.4 THz. As such, this design features a much shorter ridge gap than previous VECSELs.

Candidate Active Region

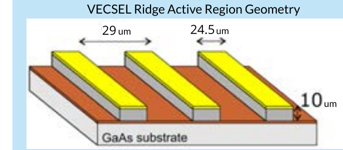
The VECSEL will be fabricated on an existing wafer design (VB0988) which has a maximum current density of about 1000 A/cm^2. Given a fill factor of 84.5%, the nominal bias region diameter was chosen to be 1 mm. This implies a peak current of 6.6 A.

Possible areas of concern moving forward primarily involve thermal performance. 500 um thick diamond may not adequately dissipate heat from the bias region.



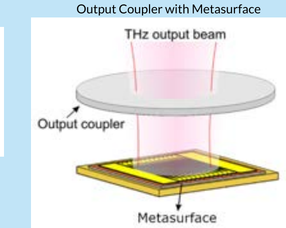
VECSEL Design

VECSEL Ridge Active Region Geometry



- Designed metasurface is a periodic array of coupled metal-metal ridges
- Chip-scale ridges consist of a layered multiple quantum well (MQW) semiconductor structure
- Laser cavity comprised of metasurface and a partially reflective output coupler
- Width and distance between ridges on the metasurface determine the resonant frequency, as does the distance of the output coupler from the metasurface

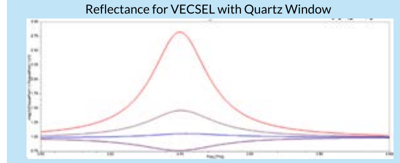
Output Coupler with Metasurface



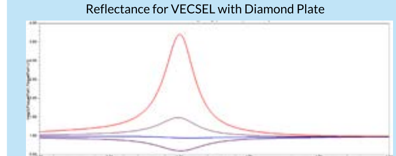
- Previous output coupler made of quartz
- Vacuum cavity separates metasurface and output coupler
- 3.4 THz is a standard frequency for which the VECSELs are designed[1]

Response at Resonant Frequency

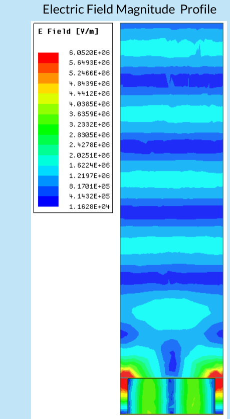
Reflectance for VECSEL with Quartz Window



Reflectance for VECSEL with Diamond Plate



Electric Field Magnitude Profile



- Simulated reflectance maintains similar values from previous design
- Expected peak reflectance at resonant frequency (3.4 THz)
- Full-width half max bandwidth is 140 GHz at 40 cm^{-1} gain
- Free spectral range (FSR) is 126 GHz; single mode lasing expected

In electromagnetic simulations, the electric field profile appears uniform with no indication of diffraction. The high intensity patterns located periodically between ridges suggests that the device will behave similarly to a distributed feedback laser (DFB). A radiative pattern indicative of wave propagation in the normal direction is observed.

Acknowledgments

We would like to thank the National Science Foundation and the UCLA HSSEAS Summer Undergraduate Research Program for providing funding for and the opportunity to publish our research, as well as the UCLA Electrical Engineering Fast Track to Success Program for its continued support of undergraduate research and studies.

References

1. Xu, L., et al. "Metasurface external cavity laser." Applied Physics Letters, **107**, (2015).
2. Kubarev, V., et al. "Optical properties of CVD-diamond in terahertz and infrared ranges". Nuclear Instruments and Methods in Physics Research A, **603**, (2009).

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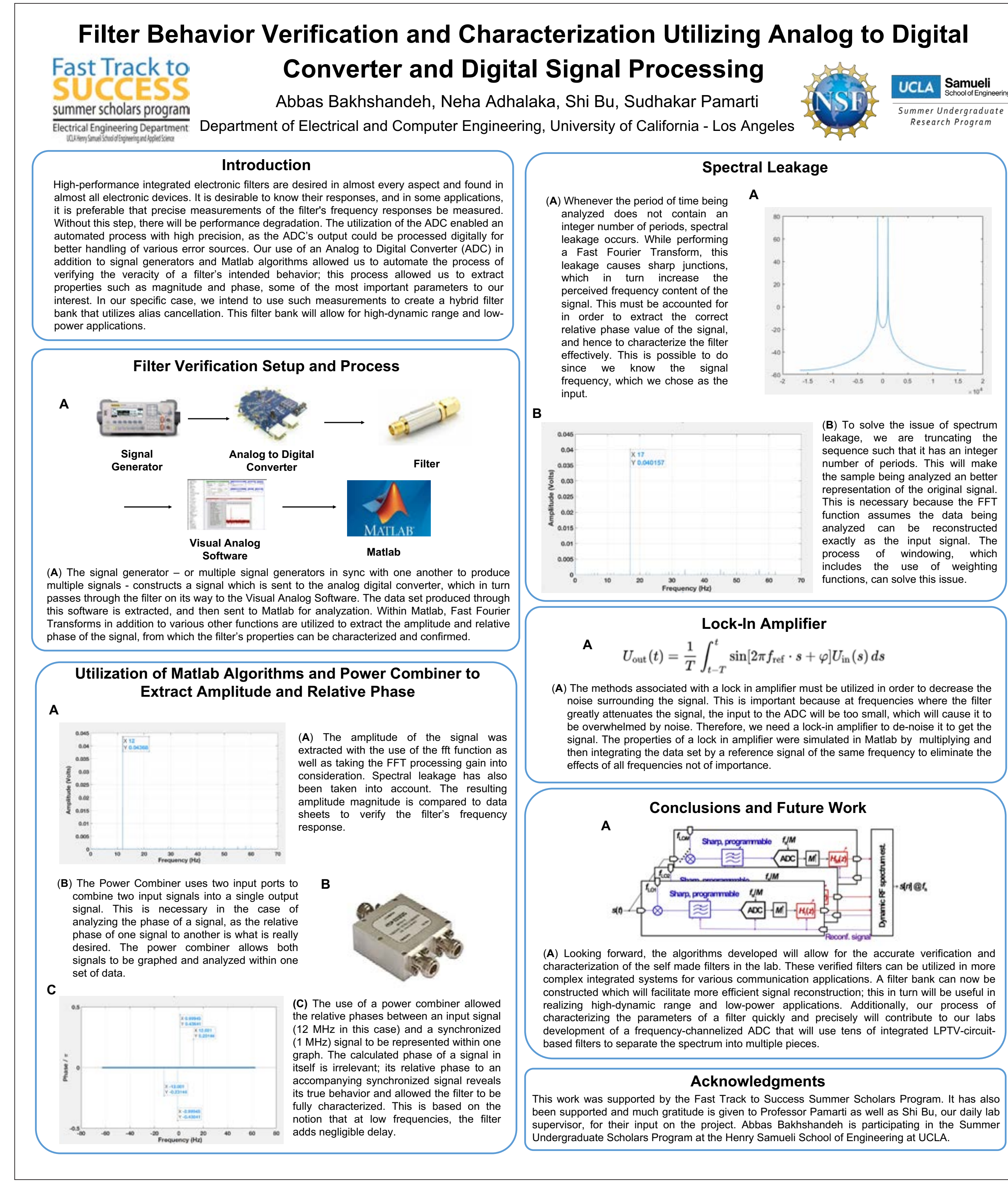
Filter Behavior Verification and Characterization Utilizing Analog to Digital Converter and Digital Signal Processing

Electronic filters are utilized almost everywhere. However, while integrated filters are demanded in modern high-complexity systems, for them to be truly useful, we need to fully characterize them with great precision. While such characterization and testing may appear to be straightforward, many difficulties arise in practice. For example, such characterization needs to be fast and accurate, with multiple aspects being measured simultaneously. Measurement equipment non-idealities, such as noise and non-linearity, had to have been addressed with careful consideration. Our utilization of an Analog to Digital Converter (ADC) enabled an automated process with high precision, as the ADC's output could be processed digitally for better handling of various error sources. Our use of an ADC in addition to signal generators and MATLAB algorithms allowed us to automate the process of verifying the veracity of a filter's intended behavior; this process allowed us to extract properties such as magnitude and phase, some of the most important parameters to our interest. These now characterized filters can be utilized in more complex integrated systems for various communication applications. For example, the aid from the automated, precise characterization of filters will allow the building of a hybrid filter bank - which would consist of tens of filters - to achieve signal reconstruction with much less difficulty, which is key to realizing a wideband frequency-channelized ADC for high-dynamic-range and low-power applications.



Filter Behavior Verification and Characterization Utilizing Analog to Digital Converter and Digital Signal Processing

Abbas Bakhshandeh, Neha Adhalaka, Shi Bu, Sudhakar Pamarti
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Introduction

High-performance integrated electronic filters are desired in almost every aspect and found in almost all electronic devices. It is desirable to know their responses, and in some applications, it is preferable that precise measurements of the filter's frequency responses be measured. Without this step, there will be performance degradation. The utilization of the ADC enabled an automated process with high precision, as the ADC's output could be processed digitally for better handling of various error sources. Our use of an Analog to Digital Converter (ADC) in addition to signal generators and Matlab algorithms allowed us to automate the process of verifying the veracity of a filter's intended behavior; this process allowed us to extract properties such as magnitude and phase, some of the most important parameters to our interest. In our specific case, we intend to use such measurements to create a hybrid filter bank that utilizes alias cancellation. This filter bank will allow for high-dynamic range and low-power applications.

Filter Verification Setup and Process

A

(**A**) The signal generator – or multiple signal generators in sync with one another to produce multiple signals - constructs a signal which is sent to the analog digital converter, which in turn passes through the filter on its way to the Visual Analog Software. The data set produced through this software is extracted, and then sent to Matlab for analyzation. Within Matlab, Fast Fourier Transforms in addition to various other functions are utilized to extract the amplitude and relative phase of the signal, from which the filter's properties can be characterized and confirmed.

Utilization of Matlab Algorithms and Power Combiner to Extract Amplitude and Relative Phase

A

(**A**) The amplitude of the signal was extracted with the use of the fft function as well as taking the FFT processing gain into consideration. Spectral leakage has also been taken into account. The resulting amplitude magnitude is compared to data sheets to verify the filter's frequency response.

(**B**) The Power Combiner uses two input ports to combine two input signals into a single output signal. This is necessary in the case of analyzing the phase of a signal, as the relative phase of one signal to another is what is really desired. The power combiner allows both signals to be graphed and analyzed within one set of data.

B

C

(C) The use of a power combiner allowed the relative phases between an input signal (12 MHz in this case) and a synchronized (1 MHz) signal to be represented within one graph. The calculated phase of a signal in itself is irrelevant; its relative phase to an accompanying synchronized signal reveals its true behavior and allowed the filter to be fully characterized. This is based on the notion that at low frequencies, the filter adds negligible delay.

Spectral Leakage

(**A**) Whenever the period of time being analyzed does not contain an integer number of periods, spectral leakage occurs. While performing a Fast Fourier Transform, this leakage causes sharp junctions, which in turn increase the perceived frequency content of the signal. This must be accounted for in order to extract the correct relative phase value of the signal, and hence to characterize the filter effectively. This is possible to do since we know the signal frequency, which we chose as the input.

A

B

(**B**) To solve the issue of spectrum leakage, we are truncating the sequence such that it has an integer number of periods. This will make the sample being analyzed an better representation of the original signal. This is necessary because the FFT function assumes the data being analyzed can be reconstructed exactly as the input signal. The process of windowing, which includes the use of weighting functions, can solve this issue.

Lock-In Amplifier

A

$$U_{\text{out}}(t) = \frac{1}{T}\int_{t-T}^{t} \sin[2\pi f_{\text{ref}} \cdot s + \varphi] U_{\text{in}}(s)\, ds$$

(**A**) The methods associated with a lock in amplifier must be utilized in order to decrease the noise surrounding the signal. This is important because at frequencies where the filter greatly attenuates the signal, the input to the ADC will be too small, which will cause it to be overwhelmed by noise. Therefore, we need a lock-in amplifier to de-noise it to get the signal. The properties of a lock in amplifier were simulated in Matlab by multiplying and then integrating the data set by a reference signal of the same frequency to eliminate the effects of all frequencies not of importance.

Conclusions and Future Work

A

(**A**) Looking forward, the algorithms developed will allow for the accurate verification and characterization of the self made filters in the lab. These verified filters can be utilized in more complex integrated systems for various communication applications. A filter bank can now be constructed which will facilitate more efficient signal reconstruction; this in turn will be useful in realizing high-dynamic range and low-power applications. Additionally, our process of characterizing the parameters of a filter quickly and precisely will contribute to our labs development of a frequency-channelized ADC that will use tens of integrated LPTV-circuit-based filters to separate the spectrum into multiple pieces.

Acknowledgments

This work was supported by the Fast Track to Success Summer Scholars Program. It has also been supported and much gratitude is given to Professor Pamarti as well as Shi Bu, our daily lab supervisor, for their input on the project. Abbas Bakhshandeh is participating in the Summer Undergraduate Scholars Program at the Henry Samueli School of Engineering at UCLA.

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Algorithmic Research in Network Infromation Flow Laboratory

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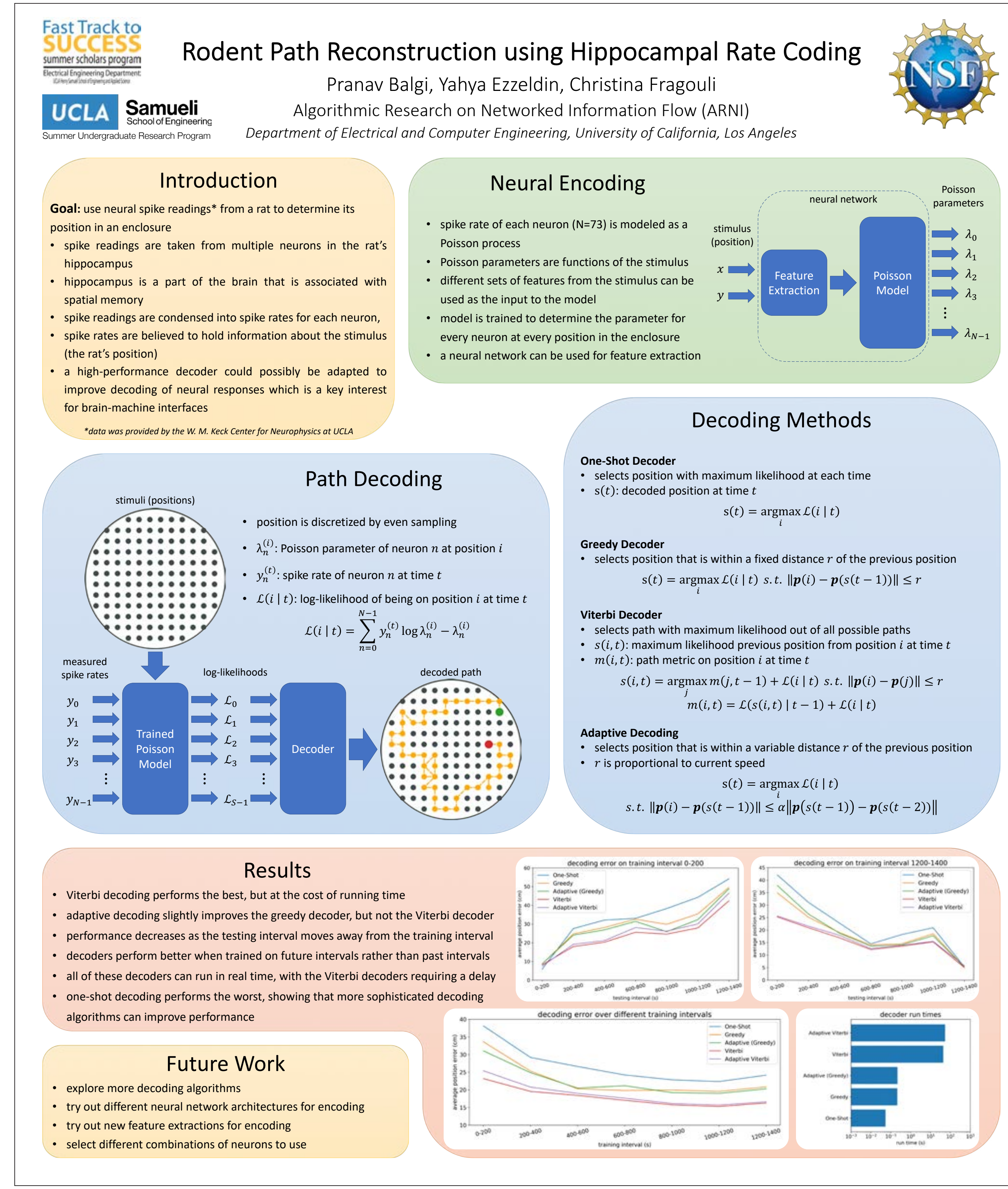
Rodent Path Reconstruction using Hippocampal Rate Coding

The goal of this project is to use neural spike readings from a rat to determine its position in an enclosure. The spike readings are taken from several neurons in the hippocampus, a part of the brain that is associated with spatial memory. The spike readings are condensed into spike rates for each neuron, which are believed to hold information about the stimulus (the rat's position). The spike rate of each neuron is modeled as a Poisson process with an unknown parameter that is a function of the stimulus. A neural network is used to determine the parameter for every neuron at every position in the enclosure. Different sets of features from the stimulus can be used as the input to the neural network. The parameters and spike rate data are then fed into a decoder to reconstruct the original path. There are many different feature extractions, neural network architectures, and decoding schemes that can be used in this framework. The goal is to select the features, design the neural network, and build the decoder that will minimize error in the reconstructed path. Some of the decoding algorithms that have been explored in this project include one-shot decoding, greedy decoding, Viterbi decoding, and adaptive decoding. A high-performance decoder could possibly be adapted to improve brain-machine interfaces.



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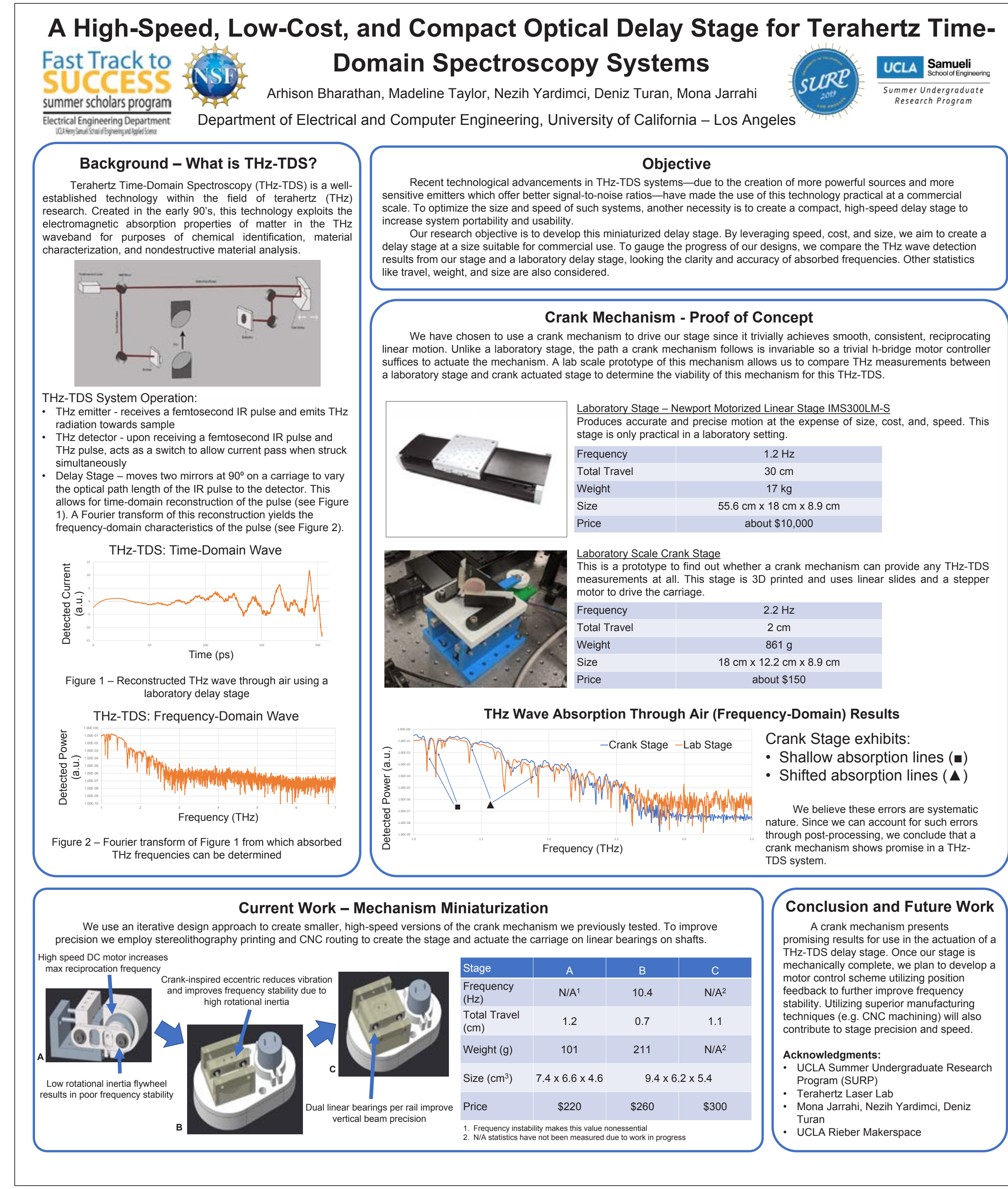
A High-Speed, Low-Cost, and Compact Optical Delay Stage for Terahertz Time-Domain Spectroscopy Systems

Terahertz Time-Domain Spectroscopy (THz-TDS) is an application of the terahertz band of the electromagnetic spectrum with advanced capabilities in chemical identification, material characterization, and nondestructive material analysis. Recent developments in THz emitter and detector technology have established improved signal-to-noise ratios within these systems, increasing the viability of THz-TDS in commercial applications. However, the weight and speed of these systems are also limited by a component known as the delay stage, a mechanical device used to vary laser optical path length. The focus of our research has been to create a miniaturized, high-speed delay stage to address this need.

While laboratory delay stages offer sub-micron accuracies, these systems are often large and expensive due to the extra functionality they provide. We have opted to explore alternative mechanisms to achieve compact and cost-effective designs that suit our application. Utilizing 3D printing and machining, we have created prototype stages using crank and crank-inspired mechanisms that achieve reciprocation frequencies of 10.4 Hz (as compared to 1.2 Hz by a laboratory stage). Through comparisons of THz-TDS results between a laboratory stage and our stages in the clarity and accuracy of absorbed THz waves measured through air, we have also been able to classify the efficacy of each iteration of our device. Looking at areas other than performance, our stages are lighter (211 g to 17 kg) and cheaper (about $200 to $10k) as well.



A High-Speed, Low-Cost, and Compact Optical Delay Stage for Terahertz Time-Domain Spectroscopy Systems

Arhison Bharathan, Madeline Taylor, Nezih Yardimci, Deniz Turan, Mona Jarrahi
Department of Electrical and Computer Engineering, University of California – Los Angeles

Fast Track to SUCCESS summer scholars program
Electrical Engineering Department
UCLA Samueli School of Engineering
Summer Undergraduate Research Program

Background – What is THz-TDS?

Terahertz Time-Domain Spectroscopy (THz-TDS) is a well-established technology within the field of terahertz (THz) research. Created in the early 90's, this technology exploits the electromagnetic absorption properties of matter in the THz waveband for purposes of chemical identification, material characterization, and nondestructive material analysis.

THz-TDS System Operation:

- THz emitter - receives a femtosecond IR pulse and emits THz radiation towards sample
- THz detector - upon receiving a femtosecond IR pulse and THz pulse, acts as a switch to allow current pass when struck simultaneously
- Delay Stage – moves two mirrors at 90º on a carriage to vary the optical path length of the IR pulse to the detector. This allows for time-domain reconstruction of the pulse (see Figure 1). A Fourier transform of this reconstruction yields the frequency-domain characteristics of the pulse (see Figure 2).

Figure 1 – Reconstructed THz wave through air using a laboratory delay stage

Figure 2 – Fourier transform of Figure 1 from which absorbed THz frequencies can be determined

Objective

Recent technological advancements in THz-TDS systems—due to the creation of more powerful sources and more sensitive emitters which offer better signal-to-noise ratios—have made the use of this technology practical at a commercial scale. To optimize the size and speed of such systems, another necessity is to create a compact, high-speed delay stage to increase system portability and usability.

Our research objective is to develop this miniaturized delay stage. By leveraging speed, cost, and size, we aim to create a delay stage at a size suitable for commercial use. To gauge the progress of our designs, we compare the THz wave detection results from our stage and a laboratory delay stage, looking the clarity and accuracy of absorbed frequencies. Other statistics like travel, weight, and size are also considered.

Crank Mechanism - Proof of Concept

We have chosen to use a crank mechanism to drive our stage since it trivially achieves smooth, consistent, reciprocating linear motion. Unlike a laboratory stage, the path a crank mechanism follows is invariable so a trivial h-bridge motor controller suffices to actuate the mechanism. A lab scale prototype of this mechanism allows us to compare THz measurements between a laboratory stage and crank actuated stage to determine the viability of this mechanism for this THz-TDS.

Laboratory Stage – Newport Motorized Linear Stage IMS300LM-S
Produces accurate and precise motion at the expense of size, cost, and, speed. This stage is only practical in a laboratory setting.

Frequency	1.2 Hz
Total Travel	30 cm
Weight	17 kg
Size	55.6 cm x 18 cm x 8.9 cm
Price	about $10,000

Laboratory Scale Crank Stage
This is a prototype to find out whether a crank mechanism can provide any THz-TDS measurements at all. This stage is 3D printed and uses linear slides and a stepper motor to drive the carriage.

Frequency	2.2 Hz
Total Travel	2 cm
Weight	861 g
Size	18 cm x 12.2 cm x 8.9 cm
Price	about $150

THz Wave Absorption Through Air (Frequency-Domain) Results

Crank Stage exhibits:

- Shallow absorption lines (■)
- Shifted absorption lines (▲)

We believe these errors are systematic nature. Since we can account for such errors through post-processing, we conclude that a crank mechanism shows promise in a THz-TDS system.

Current Work – Mechanism Miniaturization

We use an iterative design approach to create smaller, high-speed versions of the crank mechanism we previously tested. To improve precision we employ stereolithography printing and CNC routing to create the stage and actuate the carriage on linear bearings on shafts.

Stage	A	B	C
Frequency (Hz)	N/A[1]	10.4	N/A[2]
Total Travel (cm)	1.2	0.7	1.1
Weight (g)	101	211	N/A[2]
Size (cm^3)	7.4 x 6.6 x 4.6	9.4 x 6.2 x 5.4	
Price	$220	$260	$300

1. Frequency instability makes this value nonessential
2. N/A statistics have not been measured due to work in progress

Conclusion and Future Work

A crank mechanism presents promising results for use in the actuation of a THz-TDS delay stage. Once our stage is mechanically complete, we plan to develop a motor control scheme utilizing position feedback to further improve frequency stability. Utilizing superior manufacturing techniques (e.g. CNC machining) will also contribute to stage precision and speed.

Acknowledgments:

- UCLA Summer Undergraduate Research Program (SURP)
- Terahertz Laser Lab
- Mona Jarrahi, Nezih Yardimci, Deniz Turan
- UCLA Rieber Makerspace

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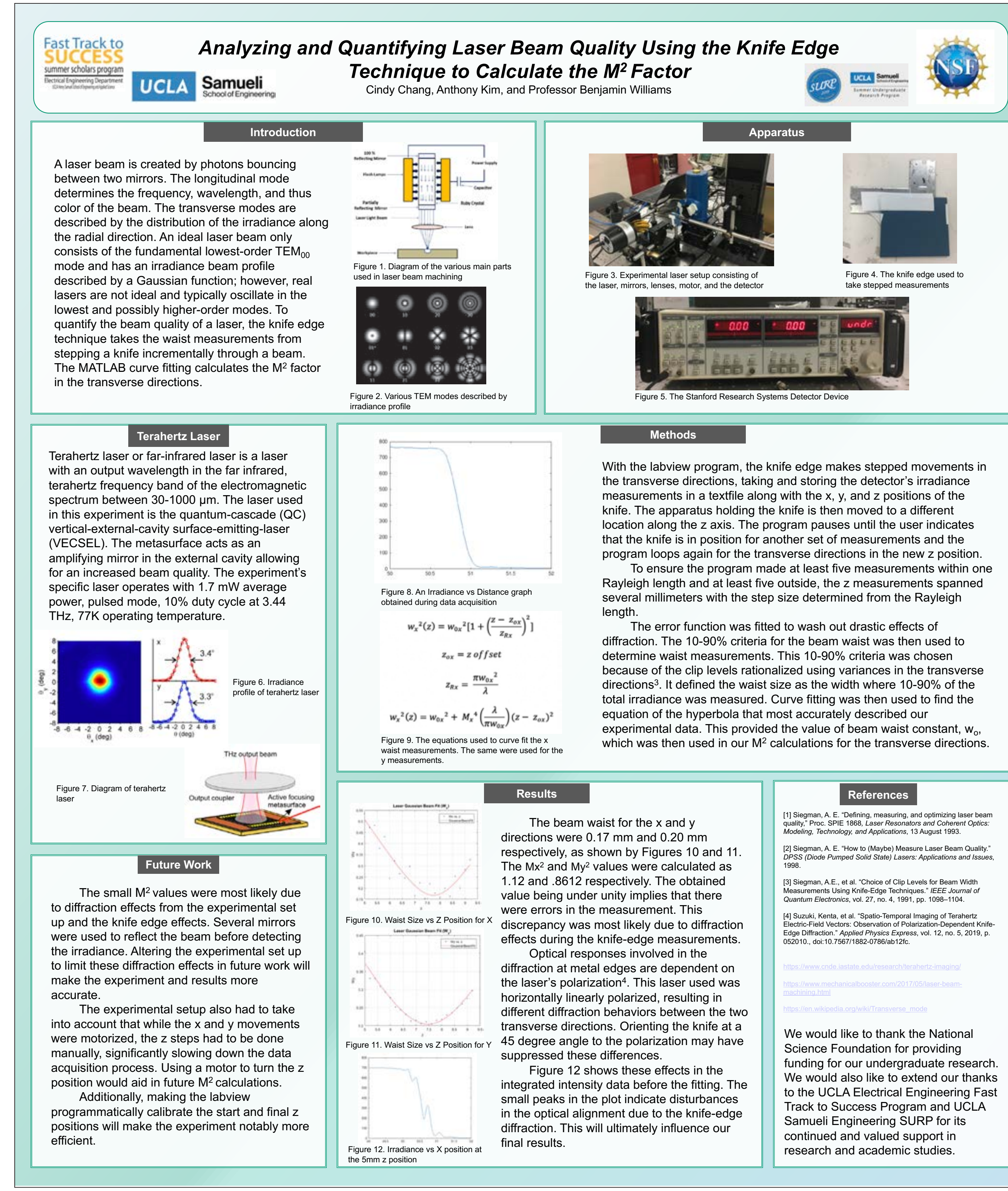
Analyzing and Quantifying Laser Beam Quality Using the Knife Edge Technique to Calculate the M^2 Factor

A laser's beam quality is a critical parameter in the performance of the laser in the laboratory or for industrial use. Describing the beam quality entails measuring the beam's spot size, a fundamental problem in laser diagnostics as laser beams are often irregular in shape. This is due to the various modes in a laser beam. The ideal Gaussian beam consists of the fundamental lowest-order TEM00 mode and has an irradiance beam profile described by a Gaussian function. We demonstrate a beam quality factor measurement of a terahertz quantum-cascade vertical external cavity surface-emitting laser (QC-VECSEL). The external cavity ideally allows for lasing at the fundamental Gaussian mode. Using a knife-edge measurement scheme, the M^2 factor can be extracted, which describes the extent to which the beam is diffraction limited.

The knife edge technique uses a converging lens to focus on the beam and makes a series of stepped measurements with a knife-edge in two different transverse directions at and around the lens's focus where the beam radius is minimized. This allows the calculation of the beam's spot size, the radius of the beam containing the majority of the power, by measuring the transmitted power with the shift of the knife in the transverse directions. By analyzing the behavior of the beam radius across the optic axis, the divergence of the beam is characterized.



Analyzing and Quantifying Laser Beam Quality Using the Knife Edge Technique to Calculate the M^2 Factor

Cindy Chang, Anthony Kim, and Professor Benjamin Williams

Introduction

A laser beam is created by photons bouncing between two mirrors. The longitudinal mode determines the frequency, wavelength, and thus color of the beam. The transverse modes are described by the distribution of the irradiance along the radial direction. An ideal laser beam only consists of the fundamental lowest-order TEM_{00} mode and has an irradiance beam profile described by a Gaussian function; however, real lasers are not ideal and typically oscillate in the lowest and possibly higher-order modes. To quantify the beam quality of a laser, the knife edge technique takes the waist measurements from stepping a knife incrementally through a beam. The MATLAB curve fitting calculates the M^2 factor in the transverse directions.

Figure 1. Diagram of the various main parts used in laser beam machining

Figure 2. Various TEM modes described by irradiance profile

Apparatus

Figure 3. Experimental laser setup consisting of the laser, mirrors, lenses, motor, and the detector

Figure 4. The knife edge used to take stepped measurements

Figure 5. The Stanford Research Systems Detector Device

Terahertz Laser

Terahertz laser or far-infrared laser is a laser with an output wavelength in the far infrared, terahertz frequency band of the electromagnetic spectrum between 30-1000 μm. The laser used in this experiment is the quantum-cascade (QC) vertical-external-cavity surface-emitting-laser (VECSEL). The metasurface acts as an amplifying mirror in the external cavity allowing for an increased beam quality. The experiment's specific laser operates with 1.7 mW average power, pulsed mode, 10% duty cycle at 3.44 THz, 77K operating temperature.

Figure 6. Irradiance profile of terahertz laser

Figure 7. Diagram of terahertz laser

Figure 8. An Irradiance vs Distance graph obtained during data acquisition

$$w_x^2(z) = w_{0x}^2\left[1 + \left(\frac{z - z_{0x}}{z_{Rx}}\right)^2\right]$$

$$z_{0x} = z\ offset$$

$$z_{Rx} = \frac{\pi w_{0x}^2}{\lambda}$$

$$w_x^2(z) = w_{0x}^2 + M_x^4\left(\frac{\lambda}{\pi w_{0x}}\right)(z - z_{0x})^2$$

Figure 9. The equations used to curve fit the x waist measurements. The same were used for the y measurements.

Methods

With the labview program, the knife edge makes stepped movements in the transverse directions, taking and storing the detector's irradiance measurements in a textfile along with the x, y, and z positions of the knife. The apparatus holding the knife is then moved to a different location along the z axis. The program pauses until the user indicates that the knife is in position for another set of measurements and the program loops again for the transverse directions in the new z position.

To ensure the program made at least five measurements within one Rayleigh length and at least five outside, the z measurements spanned several millimeters with the step size determined from the Rayleigh length.

The error function was fitted to wash out drastic effects of diffraction. The 10-90% criteria for the beam waist was then used to determine waist measurements. This 10-90% criteria was chosen because of the clip levels rationalized using variances in the transverse directions[3]. It defined the waist size as the width where 10-90% of the total irradiance was measured. Curve fitting was then used to find the equation of the hyperbola that most accurately described our experimental data. This provided the value of beam waist constant, w_o, which was then used in our M^2 calculations for the transverse directions.

Future Work

The small M^2 values were most likely due to diffraction effects from the experimental set up and the knife edge effects. Several mirrors were used to reflect the beam before detecting the irradiance. Altering the experimental set up to limit these diffraction effects in future work will make the experiment and results more accurate.

The experimental setup also had to take into account that while the x and y movements were motorized, the z steps had to be done manually, significantly slowing down the data acquisition process. Using a motor to turn the z position would aid in future M^2 calculations.

Additionally, making the labview programmatically calibrate the start and final z positions will make the experiment notably more efficient.

Results

Figure 10. Waist Size vs Z Position for X

Figure 11. Waist Size vs Z Position for Y

Figure 12. Irradiance vs X position at the 5mm z position

The beam waist for the x and y directions were 0.17 mm and 0.20 mm respectively, as shown by Figures 10 and 11. The M_x^2 and M_y^2 values were calculated as 1.12 and .8612 respectively. The obtained value being under unity implies that there were errors in the measurement. This discrepancy was most likely due to diffraction effects during the knife-edge measurements.

Optical responses involved in the diffraction at metal edges are dependent on the laser's polarization[4]. This laser used was horizontally linearly polarized, resulting in different diffraction behaviors between the two transverse directions. Orienting the knife at a 45 degree angle to the polarization may have suppressed these differences.

Figure 12 shows these effects in the integrated intensity data before the fitting. The small peaks in the plot indicate disturbances in the optical alignment due to the knife-edge diffraction. This will ultimately influence our final results.

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Implementing Kinematic Prediction via Physics-Guided Neural Networks

Physics-guided neural networks (PGNNs) are crucial for modeling resistive behaviors in real- life scenarios ranging from vehicle tracking to aerial trajectories. In prior papers, bounding box construction for videos would entail construction for every individual frame, hindering progress in terms of speed-up without significant computational power. This paper aims to bridge the divide between inage and video object detection, utilizing kinematic priors to predict the motion of subjects via the incorporation of affine transformations and per- spective consideration (horizon, side-to-side, overhead, etc.). Approaches based on optical flow algorithms and tubelet architectures are considered, and blended with physical mod- ules to harness spatiotemporal coherence among individual frames. Py-Torch 1.0 acts as the framework for code development, and all code is expected to be open-source for future development.

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Physics-Based Object Temporal Localization Via Video Segmentation

The field of object detection has seen much advancements over the past years, especially in videos with the implementation and improvements of architectures such as Optical Flow, Tubelets, and Temporal Action Localization. However, such methods are still limited in their speed, efficiency, and accuracy, with the current fastest method running at an average of two frames per second. Thus, we propose the usage of the Physics Guided Neural Network (PGNN) to aid this task. By specifically tailoring this to detection of cars we hope to produce a naive form of detection that can track and solve transformations (i.e. scale, sheer, and direction) of cars as they travel down a road. Using segmentation, we would then be able to establish instances of the cars as apply a physics model and determine each object's trajectory based on the previous frames of the object's path. The application of the physics model will serve to reduce the computational requirements of previous methods and allow for a more accurate prediction of an object's temporal location.

Implementing Kinematic Prediction via Physics-Guided Neural Networks

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Using Physics-Based Machine Learning to Track Objects

Physics-guided neural networks (PGNNs) are crucial for modeling resistive behaviors in real life scenarios ranging from vehicle tracking to aerial trajectories. In prior papers, bounding box construction for videos would entail construction for every individual frame, hindering progress in terms of speed without significant computational power. This paper aims to bridge the divide between image and video object detection, utilizing kinematic priors to predict the motion of subjects via the incorporation of affine transformations and perspective consideration (horizon, side-to-side, overhead, etc.). Approaches based on optical flow algorithms and tubelet architectures are considered and blended with physical modules to harness spatiotemporal coherence among individual frames. PyTorch 1.0 acts as the framework for code development and all code is expected to be open-source for future development.

Regional Convolutional Neural Networks

Figure 1 : Improvements such as clearer annotations and bounding box representations were made on a Faster R-CNN framework with 20 different classifications of objects. The physics model resulted from this framework of Faster R-CNN.

Dataset

Applications of physics-based calculations on the Faster R-CNN framework were tested on a self-made dataset of videos that captured optimal scenarios, including drops, tosses, and object sliding on surfaces to model the effects of gravity, resistance, and object motion. The added complexity of object occlusion was captured for the purpose of modeling realistic difficulties in object detection and motion prediction.

Physics-Based Model

Frame
Bounding box coordinates
Class labels
Confidence probabilities

For Frames 1 and 2, Frames 2 and 3

Calculate Euclidean distances between bounding boxes of the same class

Remove "camera motion" if all subjects move consistently between frames

Identify the shortest distance between bounding boxes of the same class (velocity).

Find the change in velocity between two pairs of frames (acceleration).

For next 17 frames

Use kinematic equations to predict locations of future bounding boxes.

The midpoint of a bounding box (above) was used to calculate distance

If ground truth is close to the predicted bounding box, increase confidence probabilities.

If ground truth is far from the predicted bounding box, decrease confidence probabilities.

Future Plans

The proposed physics model performs with high confidence values in the ideal scenarios created within the dataset. Expectations for future improvements include higher efficiency rates, faster processing rates, greater accuracy between multiple objects, and more accurate predictions for accounted complexities such as occlusions, lighting, and camera motion.

Limitations of current model:

Inability to account for changing acceleration
Inability to predict object motion with occlusions
Prediction model accounts for only 2D object transformations.
Unidentified objects lack physics-based machine learning

Applications:

Self-Driving
Defense Industry
Autonomous Drones
Movement Prediction

Preliminary Results

Figure 4: Bottle detection without physics-based learning (left) and with physics-based learning (right)

Figure 5: Multiple object detection without physics-based learning (left) and with physics-based learning (right)

The physics-based model results indicate significant increases in the accuracy of the model when compared with simply the Faster R-CNN framework. Faster R-CNN with physics-based machine learning increases the confidence of object detection and removes classification errors for objects.

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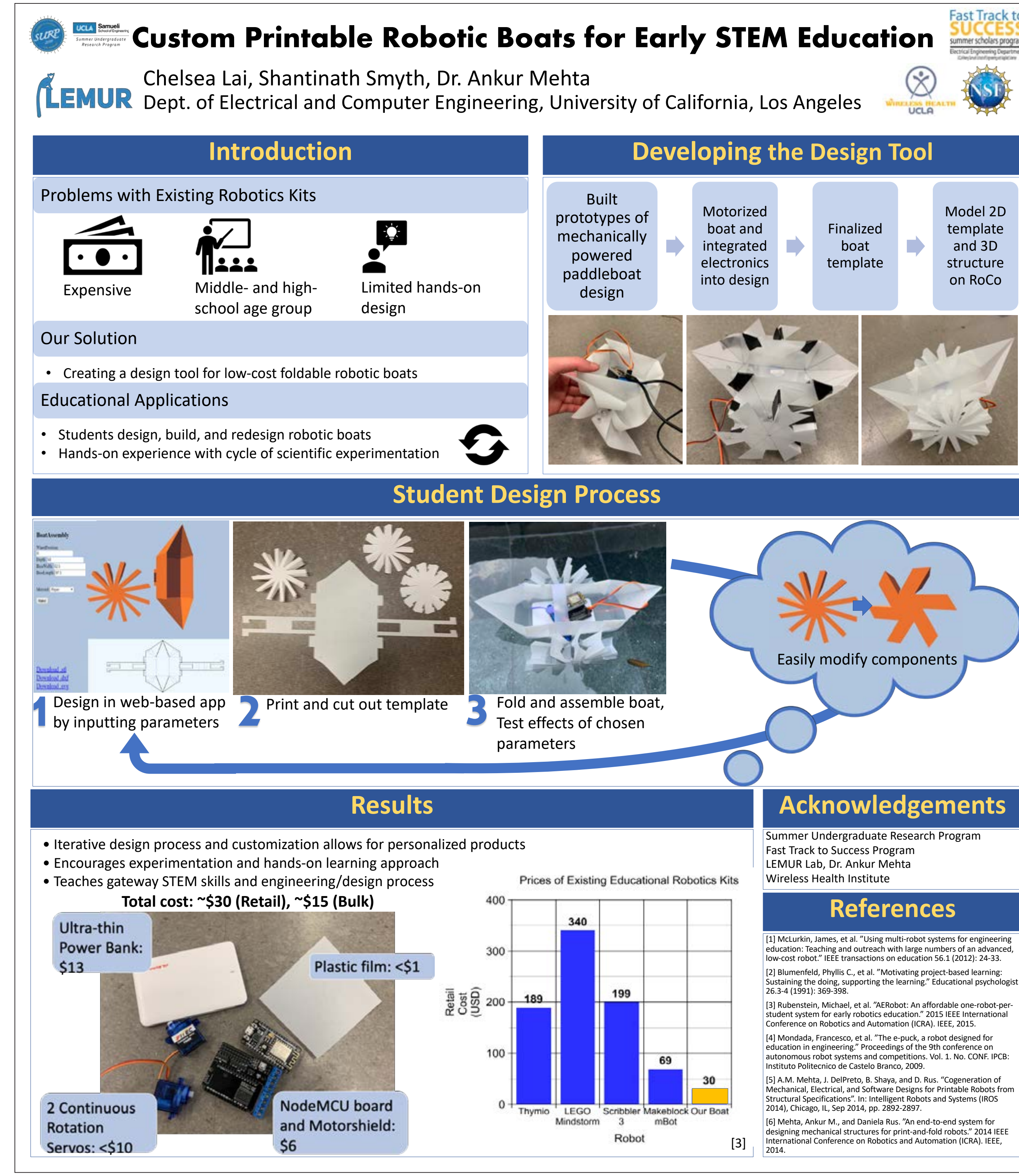
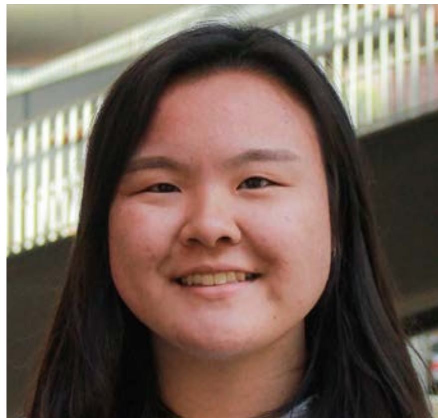
Custom Printable Robotic Boats for Early STEM Education

Robotics engages students in multiple disciplines of engineering, which is increasingly important in our technology-based society. However, existing robotics kits are mostly geared toward middle- and high- school students and either cost hundreds or thousands of dollars or have limited hands-on design capabilities. This leaves customizable robotics unaffordable to many schools, as well as neglects to introduce robots to impressionable elementary-age children. Our project focused on concurrently addressing three concerns: cost, age group, and creative potential. We developed a modifiable template for an affordable robot that students design themselves, supporting a project-based learning approach, with the goal of inspiring interest in STEM in kindergartners.

Since most robotics kits are cars, we designed a robotic boat and a web-based app, which students use to create and steer the boat. One boat is made of a flat sheet of plastic folded into a 3D structure, with basic electronics propelling the vehicle, and costs under $40 total. In the app, powered by Robot Compiler technology, students change parameters on the boat to see the effect on the 2D printable template and 3D model of the finished boat. This focus on customization encourages iterative design and engages students firsthand in the engineering innovation process. Students have flexibility in designing their robots down to the component level, fostering a sense of ownership over their project and resulting in a more self-motivated learning experience.





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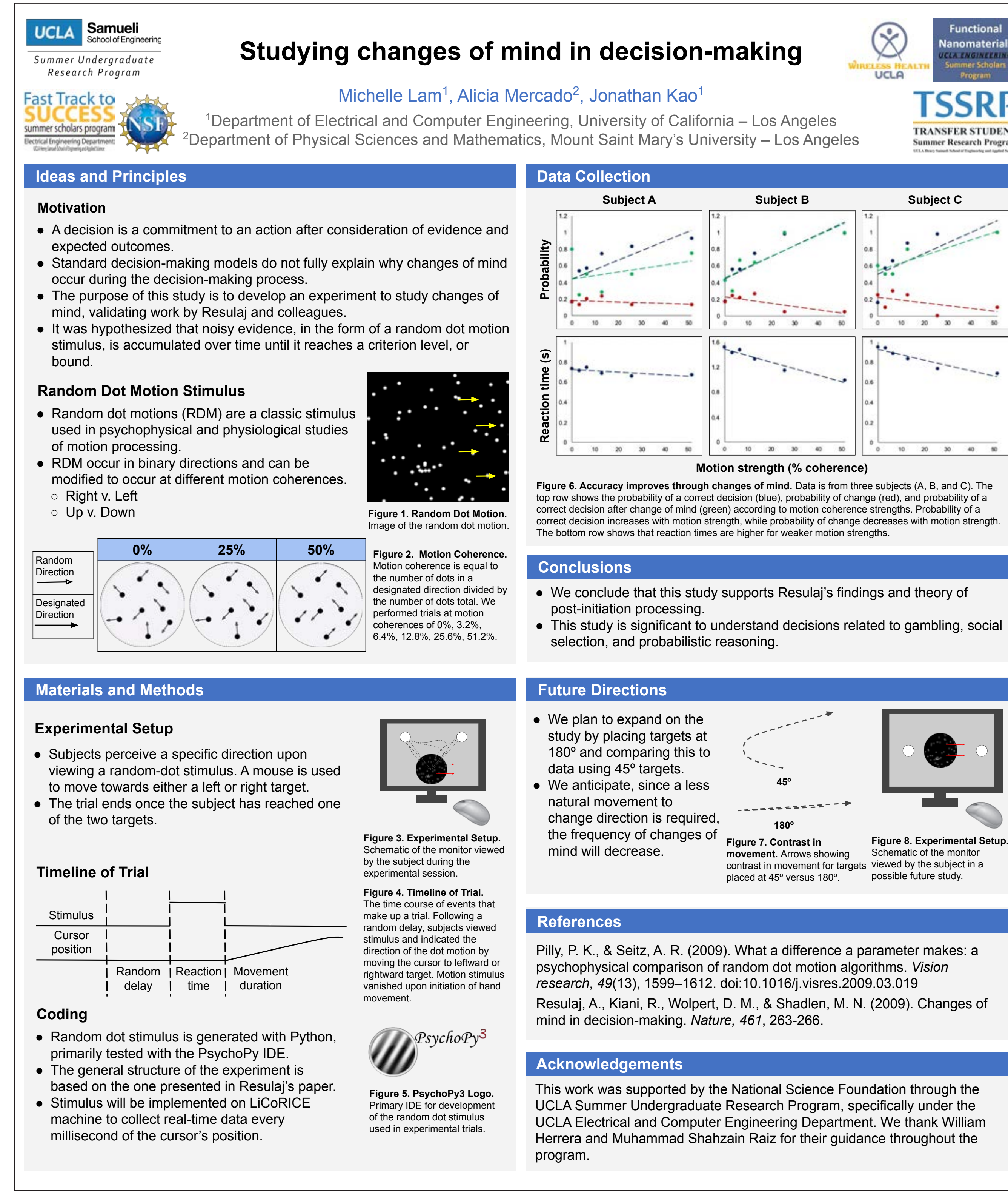
Studying changes of mind in decision-making

A decision is a commitment to an action after consideration of evidence and expected outcomes. The brain deliberates on available evidence to yield an action or decision. However, during cognition, we often change our minds; standard decision-making models do not fully explain why these changes of mind occur. The purpose of this study is to develop an experiment to study changes of mind, validating work by Resulaj and colleagues. It was hypothesized that noisy evidence, in the form of a random dot motion stimulus, is accumulated over time until it reaches a criterion level, or bound. An initial decision is made once this criterion is achieved. While the trials were conducted, subjects made decisions about a noisy visual stimulus, and then they indicated their choice of direction by moving a joystick according to the direction inferred. The brain then exploited further information that either reversed or reaffirmed the initial decision made. We conclude that this study supports Resulaj's findings and theory of post-initiation processing. This study is significant to understand decisions related to gambling, social selection, and probabilistic reasoning.



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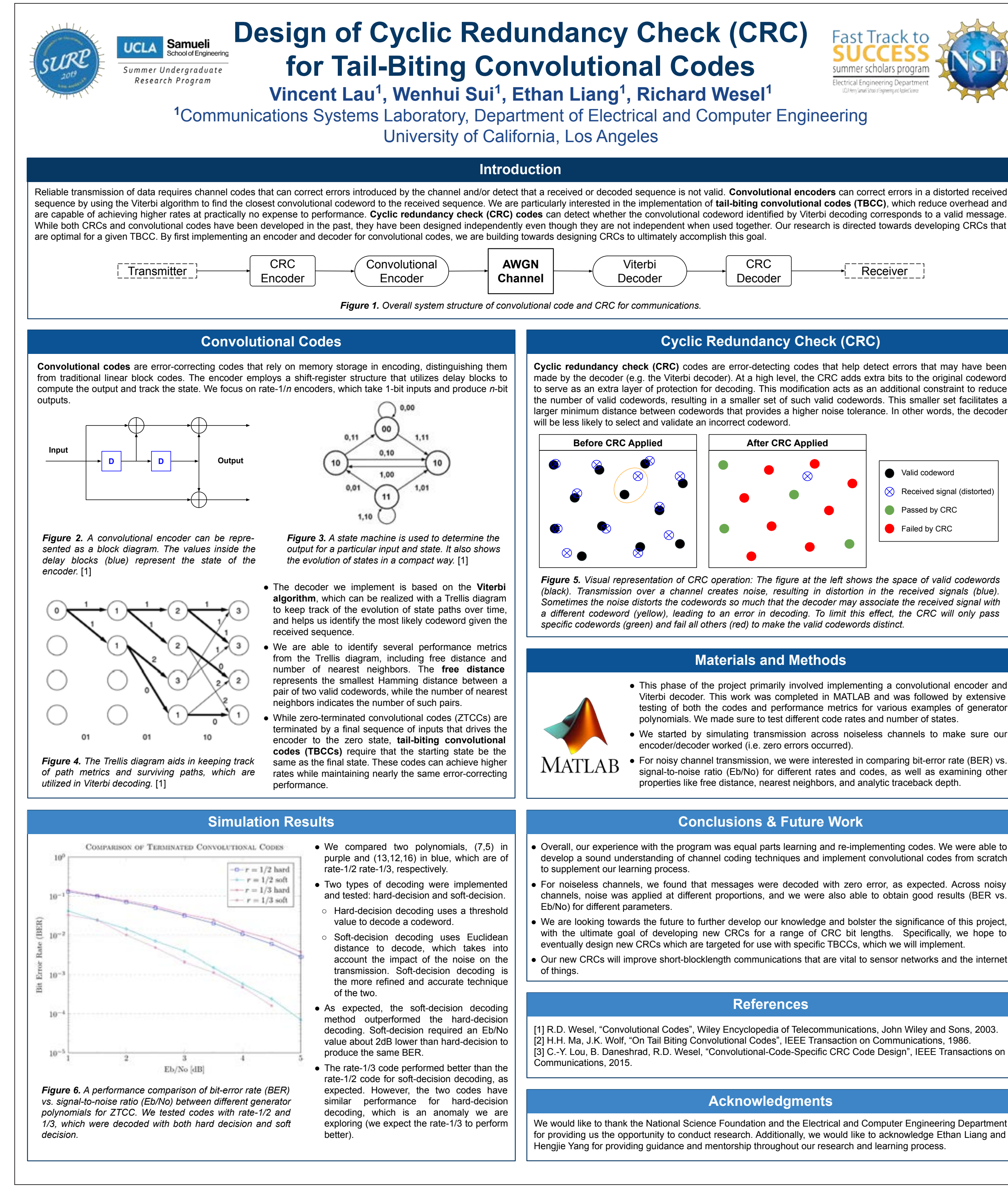
Design of Cyclic Redundancy Check (CRC) for Tail-Biting Convolutional Codes

Reliable transmission of data requires channel codes that can correct errors introduced by the channel and/or detect that a received or decoded sequence is not valid. Convolutional encoders can correct errors in a distorted received sequence by using the Viterbi algorithm to find the closest convolutional codeword to the received sequence. Cyclic redundancy check (CRC) codes can detect whether the convolutional codeword identified by Viterbi decoding corresponds to a valid message. While both CRCs and convolutional codes have been developed in the past, they have been designed independently even though they are not independent when used together. For zero-terminated convolutional codes (ZTCCs) that are terminated by a final sequence of inputs that drives the encoder to the zero state, our research group has designed CRCs that are optimal for a given ZTCC. Tail-biting convolutional codes (TBCCs) avoid the overhead caused by ZTCCs and therefore can achieve higher rates with essentially the same performance. Rather than using additional input symbols to drive the final state to zero, TBCCs enforce the constraint that the starting state is the same as the final state. Our research is directed towards developing CRCs that are optimal for a given TBCC.



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Material Characterization Through THz-Wave Spectroscopy

Terahertz (THz) wave propagation allows for a large number of technological advances in modern systems, such as larger communication bandwidth and enhanced imaging resolution. THz wave signals also prove to be valuable in the practice of spectroscopy in order to characterize materials. The reason that THz waves present new advantages comes from two characteristics of millimeter waves. Because of their large bandwidth, these types of waves offer a larger absorption data set to uniquely identify materials. Secondly, their small wave-length nature allows these waves to have very high resolution in determining the thickness of a material.

This paper lays some groundwork of THz systems as a method of spectroscopy by testing its applications to solid materials. In our research, we set up a transmit-ter and a receiver to communicate with each other at varying sub-THz frequen-cies. An object of varying material is placed along the signal path to absorb some frequencies of communication dependent on the properties of that material. Intensity of the signals is measured at both the transmitter and the receiver and recorded in the frequency domain. Through a Support Vector Machine (SVM) machine learning algorithm, absorption plots obtained from various trials are used to identify the material obstructing the signal with 95% accuracy.

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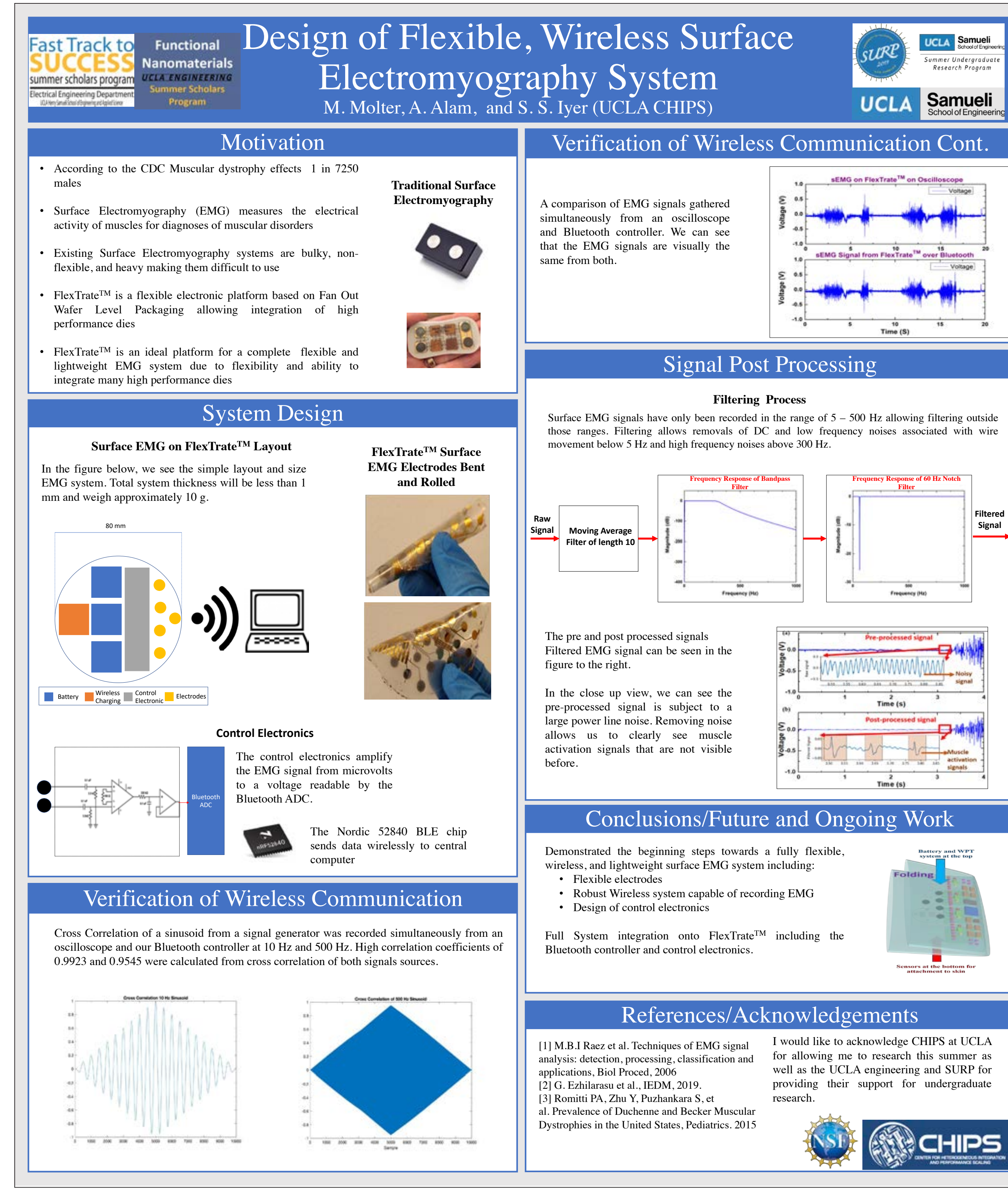
Design of Flexible, Wireless Surface Electromyography System

According to the CDC 1 in every 7,250 males are afflicted by Duchenne and Becker muscular dystrophy, a disease that affects muscle strength and leads to muscle degeneration. Surface Electromyography (EMG) is a non-invasive method used to measure muscle activity that can help in the diagnosis and treatment of musculoskeletal diseases such as muscular dystrophy. Typical Surface Electromyography machines are often bulky, rigid, and heavy which makes them difficult to use in a clinical setting, and it means they cannot be used as wearable devices. In addition, these systems are often single-channel systems which limit the spatial and temporal information that the system can gather, making readings incomplete. To help solve these issues, a full multi-channel electromyography system that is lightweight, flexible, and wireless will be integrated on FlexTrate™, a flexible electronic platform based on Fan-Out Wafer Level Packaging (FOWLP). The surface EMG will take advantage of FlexTrate™ to integrate a variety of different integrated circuit (IC) dies such as amplifiers, passive components, and a Bluetooth Low Energy (BLE) chip as well as electrodes to detect the EMG signal. For wireless communication, the Nordic nRF52840 BLE module is used for low system power. Using FlexTrate™, the overall system will be lightweight, thickness less than 1 mm, and flexible enough to conform to skin allowing for a wearable device that can be used easily in a clinical setting.



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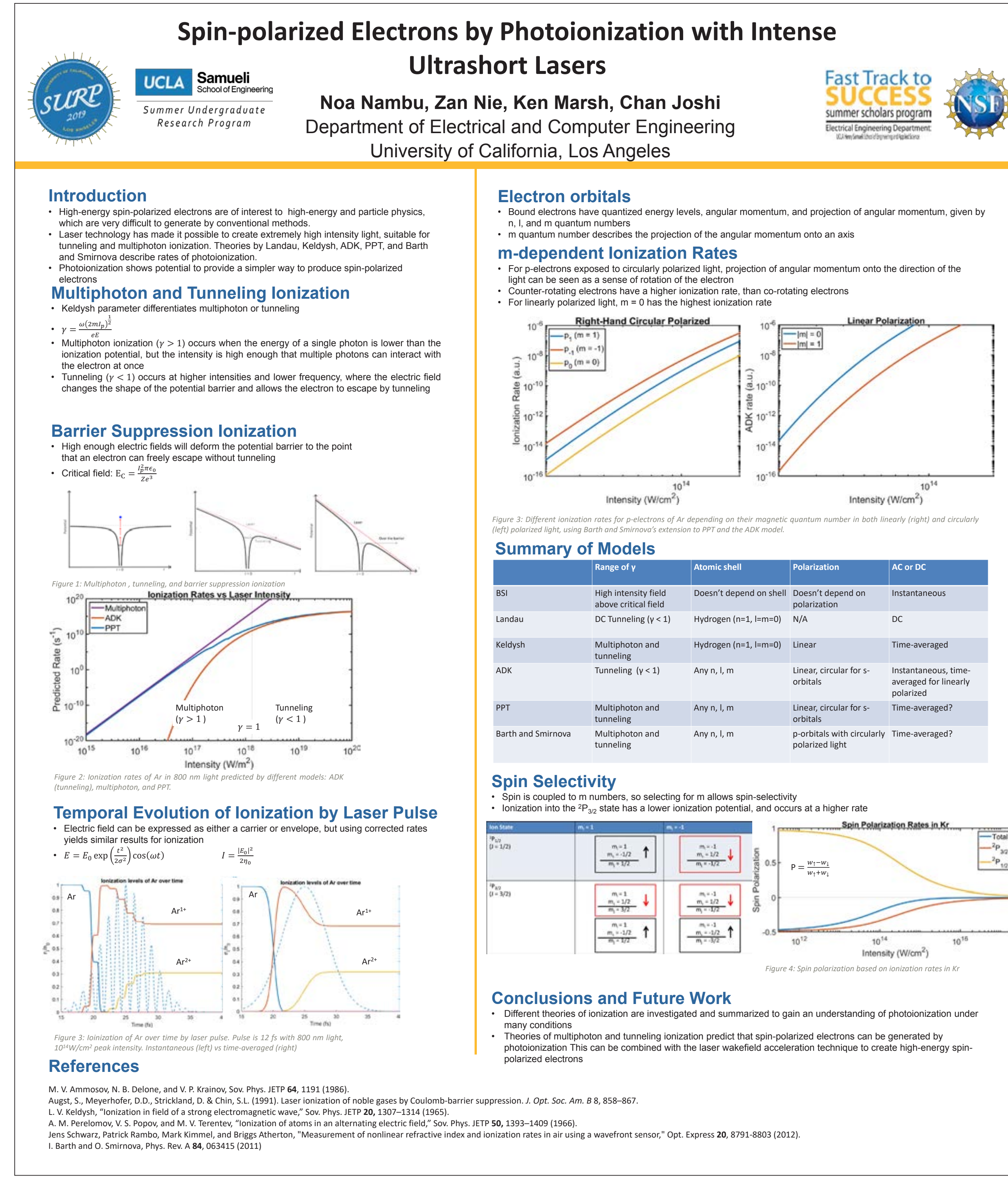
Spin-polarized Electrons by Photoionization with Intense Ultrashort Lasers

High-energy spin-polarized electrons are important for the investigation of pathways in high- energy collisions. However, generation of such electrons is difficult using conventional methods. Photoionization is a very common phenomenon that shows potential to provide a simpler way to produce spin-polarized electrons. Developments in laser technology have made it possible to create extremely high intensity light, which leads to various ionization processes. Multiphoton ionization involves the transfer of energy from multiple photons to an electron in order to surpass the ionization potential. Tunneling ionization occurs when higher field strength and lower frequencies allow the laser to be treated as an electric field which changes the shape of the potential barrier and allows the electron to escape through tunneling. The rates of ionization in these regimes have been described by several theories developed by Landau, Keldysh, ADK, PPT, and Barth and Smirnova. Different models of ionization rates were compared in order to find the areas in which they can be used to accurately describe ionization. The incorporation of magnetic and angular momentum quantum numbers into ionization rates allows for selective ionization of spin-polarized electrons, leading to predictions of up to 30% spin polarization. This may open a new avenue for the generation of high-energy, spin-polarized electrons in combination with the laser wakefield acceleration technique.



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Automated Speech Database Organization

The development of an autonomous social robot, able to deliver clinical and educational assessments to young children, has great potential to aid in the efforts of educators and help students reach age-appropriate levels of proficiency in reading and oral language skills. A study researching the feasibility of the JIBO robot for such purposes, as well as gathering data needed to improve child automated speech recognition (ASR), resulted in a large dataset of verbal interactions between the robot and children via the administration of the Goldman-Fristoe Test of Articulation (GFTA) and other language tasks. Prior to database publication, time consuming and error-prone tasks such as matching audio data with corresponding prompt-answer pairs and the notation of private information for removal must be performed. We present a design and Python implementation for software automating and simplifying such processes. As robot prompts are known and consistent, timestamps are detected in audio files using a cross- correlation approach. We propose several methods of avoiding computationally expensive operations during such a search. For files with transcripts, processing is done using both a brute force search and the SpaCy natural language processing package, the latter to identify possible private information. Results are compared and combined with those from audio processing. Finally, we propose a database organizational structure and documentation in preparation for future publication.

Automated Speech Database Organization

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Introduction

Figure 1. *The JIBO personal assistant robot was released in November of 2017.*

- What if a robot could help in the classroom?
- Recent research by Yeung et al. (2019) explored the feasibility of having the social robot JIBO (Figure 1) deliver educational assessments to young children [1].
- Additionally, data it produced was intended to be used towards developing better child automatic speech recognition (ASR), the current state of which has held back child human-robot interaction research [2].
- JIBO's administration of a letter and digit naming task and the 3rd Goldman Fristoe Tests of Articulation (GFTA-3) resulted in a large database containing 60 hours of child-robot interaction.
- This work presents an attempt to automate the necessary pre-processing of this database, as well as propose a database organizational structure.

Database

Subjects and Recordings:
- 156 children were recorded interacting with JIBO over 236 sessions.
- Sessions lasted between 5 and 40 minutes.
  - Session length varied based on child engagement and experience.
- Children were recorded in a classroom study space with limited noise.

Tasks:
- 3rd Goldman Fristoe Tests of Articulation (GFTA-3)
- Letter and digit naming task

Transcriptions:
- Full transcripts of the audio were produced by trained transcribers.
- Phonetic transcriptions were produced by trained phoneticians.

Objectives

- Create an easy to use interface for extracting/creating file information
- Automate the removal of private and sensitive data in audio
- Prepare database for publication and distribution for research

Methods

/^[Reg]ular[Ex]pression$/

SciPy NumPy SPYDER

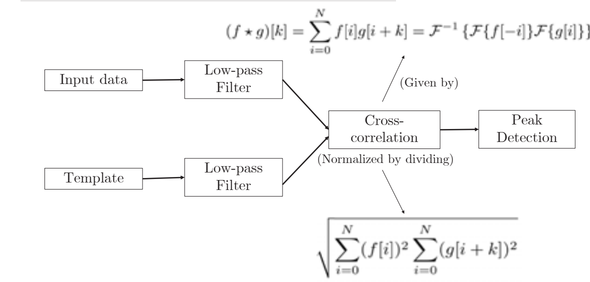
Design: Text Processing

- Processing of audio transcripts was utilized in multiple ways:
  - To extract task completion data for documentation
  - To identify private information
  - As a guiding tool when labeling and cutting audio
- Regular expression (regex) use on the predictable transcript layout allowed for such analysis.
  - Ex. "\((\d+:\d\d)\)" searches for timestamps of the form (min:sec)
- spaCy:
  - This open-source package for Natural Language Processing aided in identifying private information within files, decreasing manual work.
  - Part-of-Speech tagging and Named Entity Recognition (NER) were the two main features of the package utilized.

Design: Audio Processing

- Template-based recognition was used to perform time-delay estimation to find robot speech in an audio file (Figure 2). Results shown in Figure 3.

Figure 2. *Flow-chart of template-based recognition*



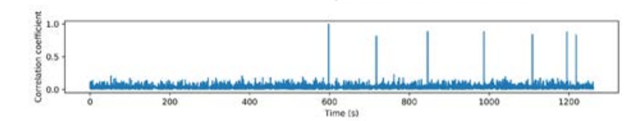


Figure 3. *Results of one normalized cross-correlation. The large peaks are matches to some JIBO voice line. A vertical axis value of 1 indicates an exact match. Due to noise and microphone placement inconsistencies, an exact match was very rare and thresholding was used to determine whether a match took place.*

Deliverables

- A new database layout was designed and accompanied with documentation using combined data from the designed processing methods.
- User interface was created for labeling and cutting audio. It decreases manual work by giving the user certain features:
  - Jump to audio containing private info or the beginning of certain tasks
  - Switch between textual and audio analysis (Figure 4) of child interviews

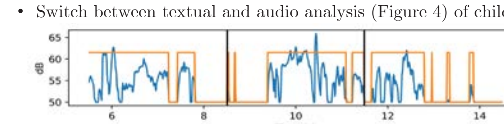


Figure 4. *A small section of a sound file. The user selected section is between the two black vertical lines. The orange sound blocks can be snapped to while scrubbing or can be ignored if fine scrubbing is desired.*

Conclusion and Future Work

- This database will assist in research for a number of diverse applications:
  - Child automatic speech recognition
  - Child speech science and linguistics
  - Human-robot interaction
- Going forward, we hope to generalize the methods for preliminary processing to all speech databases.

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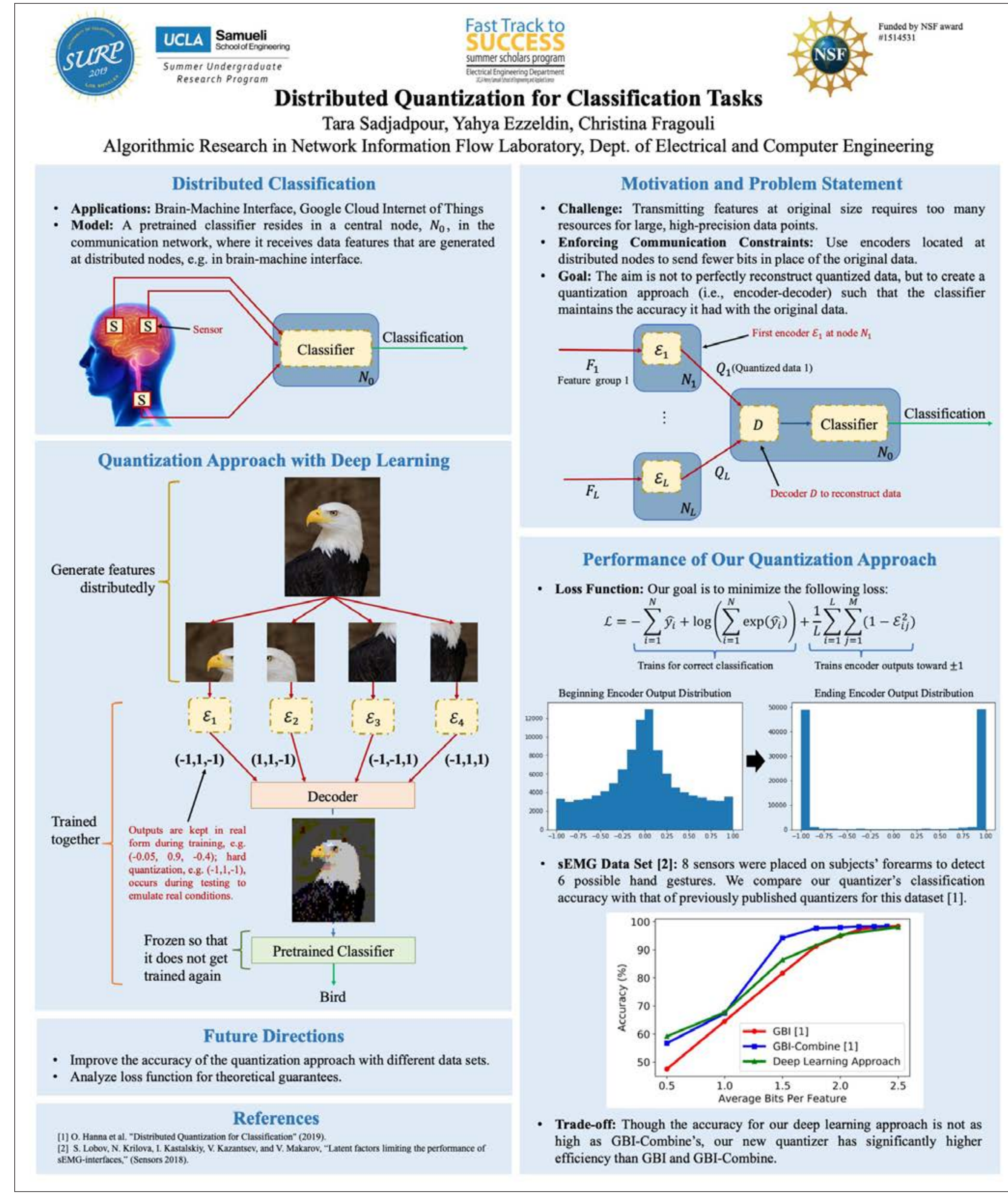
Distributed Quantization for Classification Tasks

When using quantization schemes for distributed classification, the goal is not to reconstruct quantized data perfectly; rather, it is to create a quantization approach such that the classifier maintains the accuracy it had before the large, high-precision data was quantized. If a communication quality constraint exists between different devices in the system, then the number of bits that can be used in our quantization approach is further limited. In applications, such as brain-machine interface and Google Cloud Internet of Things, there is a pretrained classifier that resides in a central node in a communication network, where it receives unclassified data that is distributedly generated. In the case of brain-machine interface, sensors are distributed on a subject's body, and thus, high-precision features are generated from these body parts. This data is then classified for an actuator to carry out some action. Previously published solutions present a greedy algorithm that uses a recursive binning technique to quantize the data. We propose a more efficient, adaptable quantization approach implemented with neural networks. This approach achieves approximately the same accuracy as the greedy algorithm on an sEMG dataset with lower time complexity.



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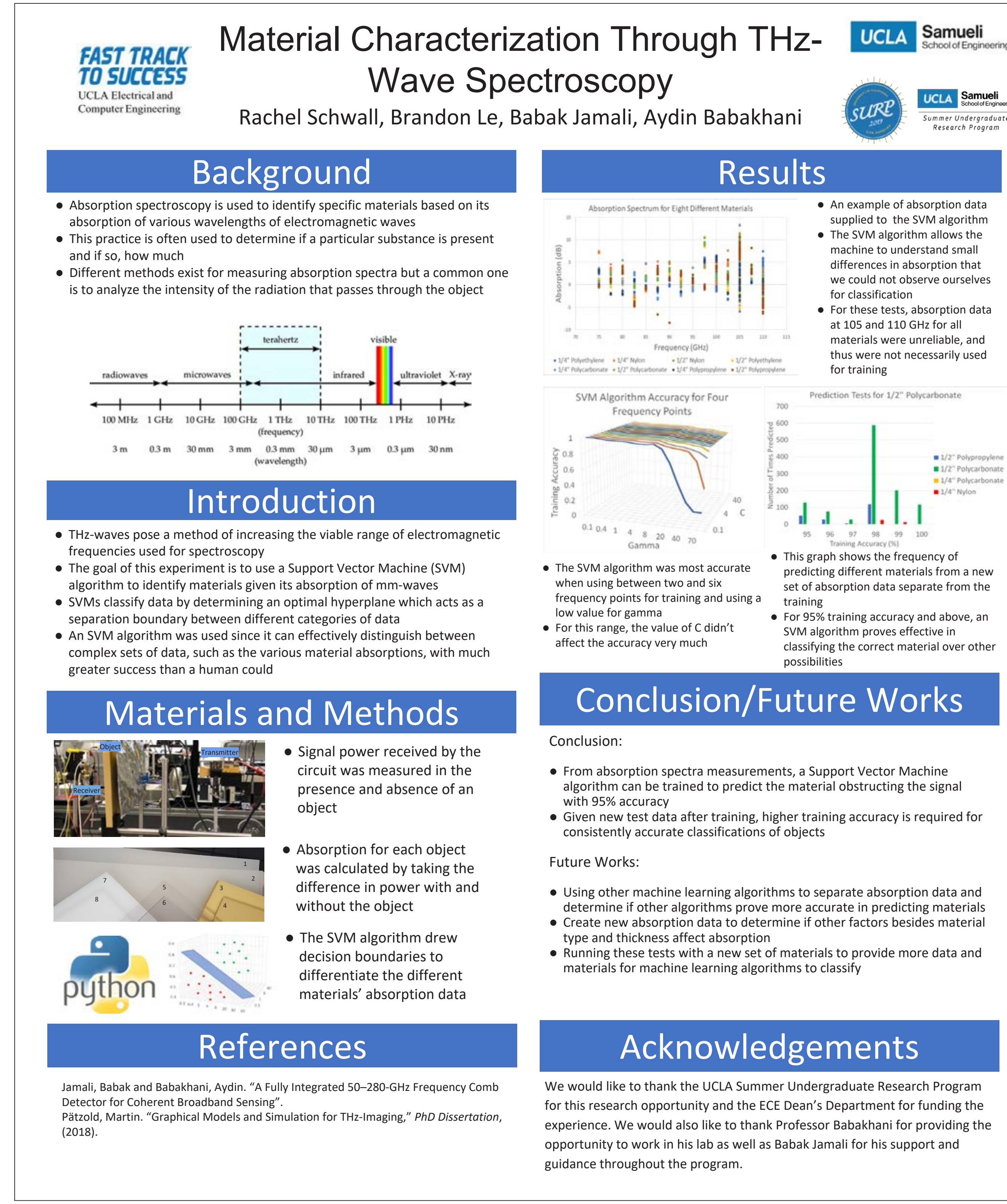
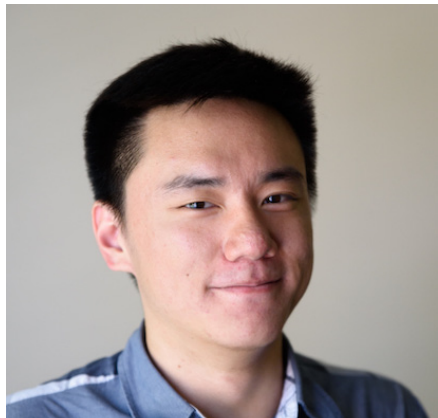
Absorption Spectroscopy Using Millimeter-Wave and Sub-Terahertz Frequencies

Sensing and retrieving data from millimeter-wave and sub-terahertz frequencies are useful for many different applications including faster data transmission in wireless communication and enhanced resolution in imaging systems. In this frequency regime, broadband systems are also useful for spectroscopy and detecting different absorption frequencies of gas molecules. A comb- based method can be used to enhance bandwidth to include these frequencies and coherent detection techniques can be used to implement a receiver that can detect them. Integrated circuits designed using this method exhibit improved bandwidth, and detection resolution as well as reduced power consumption compared to current CMOS wideband coherent receivers. One specific use for these transmitter and receiver circuits is absorption spectroscopy where the power of the signal generated by the transmitter is measured after it passes through a specific material and is recorded by the receiver. A support vector machine (SVM) algorithm can then be trained with the absorption data of multiple materials to identify a new material given its absorption data collected from the receiver. SVMs are machine learning models that can classify data by determining an optimal hyperplane which acts as a separation boundary between different categories of data. An algorithm that utilizes SVM is quite effective when it comes to distinguishing between complex sets of data since it is able to determine boundaries in the data that may not be the most obvious to the human eye.





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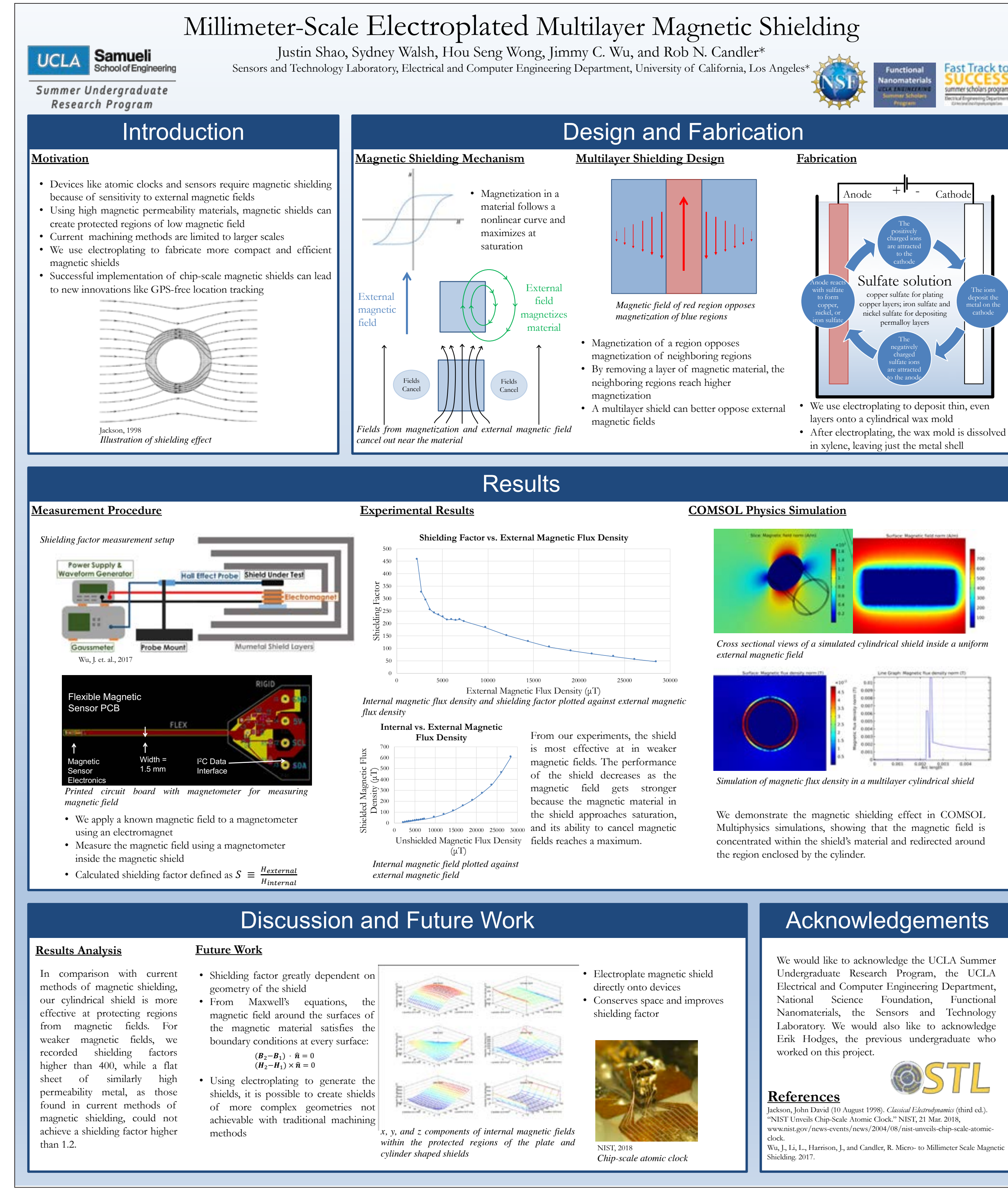
Millimeter-Scale Electroplated Multilayer Magnetic Shielding

Many devices that rely on atomic spectroscopy, like gyroscopic sensors and atomic clocks, require magnetic shielding to function as intended because of interference by external magnetic fields. Although no known material is able to stop a magnetic field, high permeability materials are able to effectively redirect magnetic field lines, creating protected regions of low magnetic field strength. Current methods of magnetic shielding involve inserting a sheet of high permeability material on a circuit board underneath a device or wrapping a region in a sheet of the high permeability material. In this project, we fabricate high performance chip-scale magnetic shields by electroplating alternating layers of nickel-iron alloy, which has a high relative permeability, and copper, which has a low relative permeability, onto a cylindrical shell. By alternating layers of high and low permeabilities, we minimize the influence of the demagnetization field, achieving a higher ability to redirect magnetic field lines. To test the shields, we use an electromagnet to generate a magnetic field and a magnetometer to measure the magnetic field inside the shield. We record the shielding factor of the shield, which is defined as the ratio of the external magnetic field strength to the internal magnetic field strength. Successful millimeter-scale shielding would allow for effective chip-scale implementation of devices that would function in external magnetic fields while conserving space.



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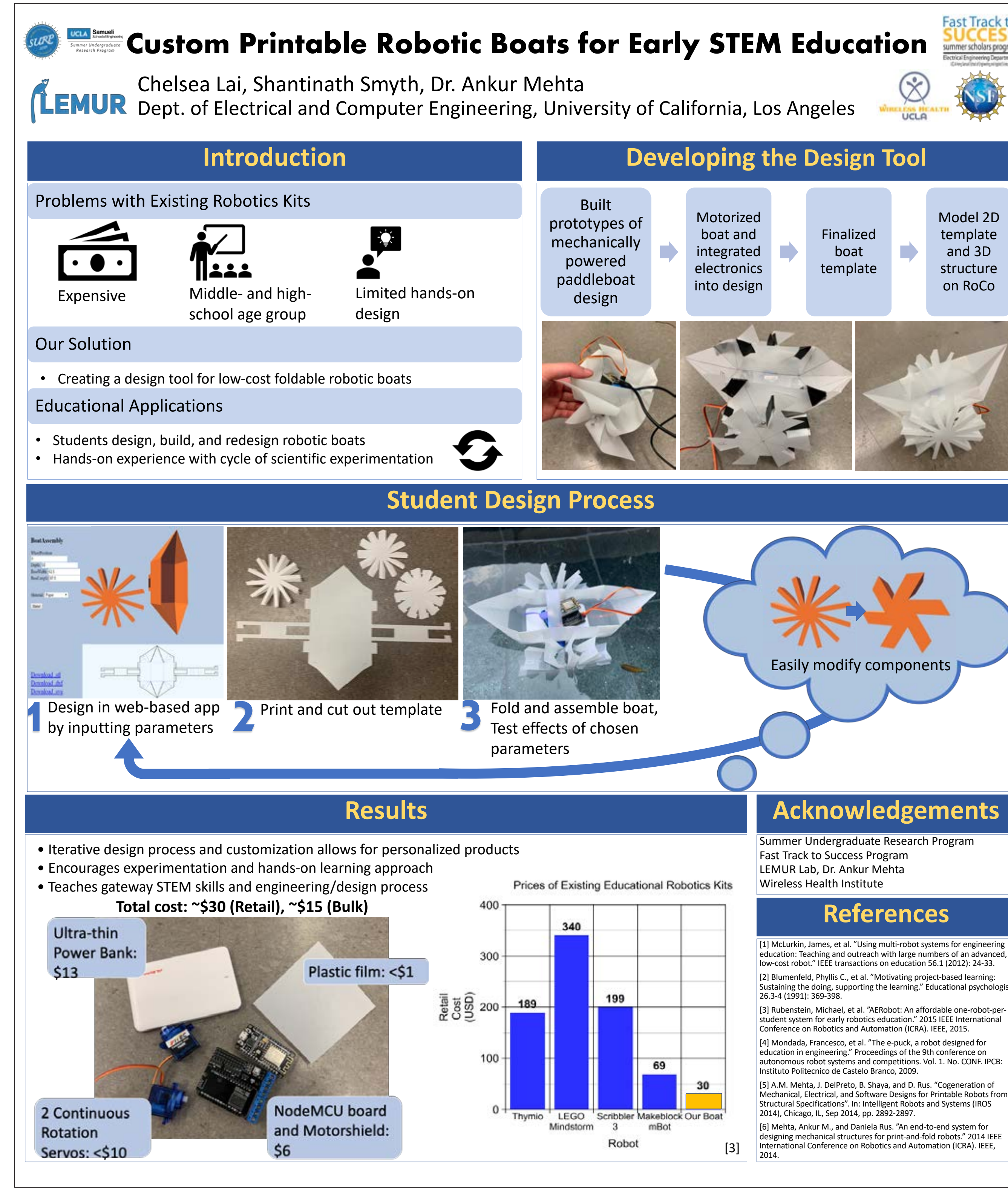
Custom Printable Robotic Boats for Early STEM Education

Robotics engages students in multiple disciplines of engineering, which is increasingly important in our technology-based society. However, existing robotics kits are mostly geared toward middle- and high- school students and either cost hundreds or thousands of dollars or have limited hands-on design capabilities. This leaves customizable robotics unaffordable to many schools, as well as neglects to introduce robots to impressionable elementary-age children. Our project focused on concurrently addressing three concerns: cost, age group, and creative potential. We developed a modifiable template for an affordable robot that students design themselves, supporting a project-based learning approach, with the goal of inspiring interest in STEM in kindergartners.

Since most robotics kits are cars, we designed a robotic boat and a web-based app, which students use to create and steer the boat. One boat is made of a flat sheet of plastic folded into a 3D structure, with basic electronics propelling the vehicle, and costs under $40 total. In the app, powered by Robot Compiler technology, students change parameters on the boat to see the effect on the 2D printable template and 3D model of the finished boat. This focus on customization encourages iterative design and engages students firsthand in the engineering innovation process. Students have flexibility in designing their robots down to the component level, fostering a sense of ownership over their project and resulting in a more self-motivated learning experience.



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Automated Speech Database Organization

The development of an autonomous social robot, able to deliver clinical and educational assessments to young children, has great potential to aid in the efforts of educators and help students reach age-appropriate levels of proficiency in reading and oral language skills. A study researching the feasibility of the JIBO robot for such purposes, as well as gathering data needed to improve child automated speech recognition (ASR), resulted in a large dataset of verbal interactions between the robot and children via the administration of the Goldman-Fristoe Test of Articulation (GFTA) and other language tasks. Prior to database publication, time consuming and error-prone tasks such as matching audio data with corresponding prompt-answer pairs and the notation of private information for removal must be performed. We present a design and Python implementation for software automating and simplifying such processes. As robot prompts are known and consistent, timestamps are detected in audio files using a cross- correlation approach. We propose several methods of avoiding computationally expensive operations during such a search. For files with transcripts, processing is done using both a brute force search and the SpaCy natural language processing package, the latter to identify possible private information. Results are compared and combined with those from audio processing. Finally, we propose a database organizational structure and documentation in preparation for future publication.

SURP 2019 — UCLA Samueli School of Engineering — Summer Undergraduate Research Program

Automated Speech Database Organization

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Introduction

Figure 1. *The JIBO personal assistant robot was released in November of 2017.*

- What if a robot could help in the classroom?
- Recent research by Yeung et al. (2019) explored the feasibility of having the social robot JIBO (Figure 1) deliver educational assessments to young children [1].
- Additionally, data it produced was intended to be used towards developing better child automatic speech recognition (ASR), the current state of which has held back child human-robot interaction research [2].
- JIBO's administration of a letter and digit naming task and the 3rd Goldman Fristoe Tests of Articulation (GFTA-3) resulted in a large database containing 60 hours of child-robot interaction.
- This work presents an attempt to automate the necessary pre-processing of this database, as well as propose a database organizational structure.

Database

Subjects and Recordings:
- 156 children were recorded interacting with JIBO over 236 sessions.
- Sessions lasted between 5 and 40 minutes.
  - Session length varied based on child engagement and experience.
- Children were recorded in a classroom study space with limited noise.

Tasks:
- 3rd Goldman Fristoe Tests of Articulation (GFTA-3)
- Letter and digit naming task

Transcriptions:
- Full transcripts of the audio were produced by trained transcribers.
- Phonetic transcriptions were produced by trained phoneticians.

Objectives

- Create an easy to use interface for extracting/creating file information
- Automate the removal of private and sensitive data in audio
- Prepare database for publication and distribution for research

Methods

/^[Reg]ular[Ex]pression$/

SciPy — NumPy — SPYDER

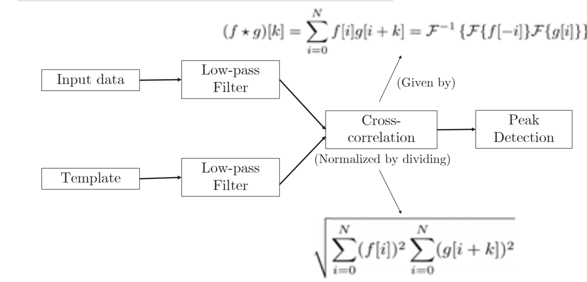
Design: Text Processing

- Processing of audio transcripts was utilized in multiple ways:
  - To extract task completion data for documentation
  - To identify private information
  - As a guiding tool when labeling and cutting audio
- Regular expression (regex) use on the predictable transcript layout allowed for such analysis.
  - Ex. “\((\d+:\d\d)\)” searches for timestamps of the form (min:sec)
- spaCy:
  - This open-source package for Natural Language Processing aided in identifying private information within files, decreasing manual work.
  - Part-of-Speech tagging and Named Entity Recognition (NER) were the two main features of the package utilized.

Design: Audio Processing

- Template-based recognition was used to perform time-delay estimation to find robot speech in an audio file (Figure 2). Results shown in Figure 3.

Figure 2. *Flow-chart of template-based recognition*



$$(f \star g)[k] = \sum_{i=0}^{N} f[i]g[i+k] = \mathcal{F}^{-1}\{\mathcal{F}\{f[-i]\}\mathcal{F}\{g[i]\}\}[k]$$

$$\sqrt{\sum_{i=0}^{N}(f[i])^2 \sum_{i=0}^{N}(g[i+k])^2}$$

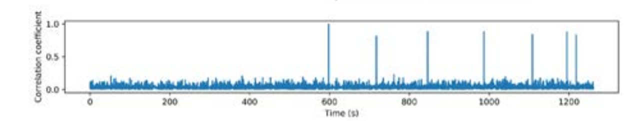


Figure 3. *Results of one normalized cross-correlation. The large peaks are matches to some JIBO voice line. A vertical axis value of 1 indicates an exact match. Due to noise and microphone placement inconsistencies, an exact match was very rare and thresholding was used to determine whether a match took place.*

Deliverables

- A new database layout was designed and accompanied with documentation using combined data from the designed processing methods.
- User interface was created for labeling and cutting audio. It decreases manual work by giving the user certain features:
  - Jump to audio containing private info or the beginning of certain tasks
  - Switch between textual and audio analysis (Figure 4) of child interviews

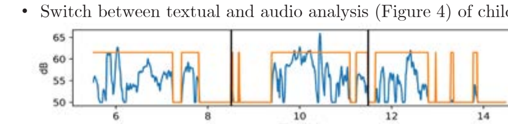


Figure 4. *A small section of a sound file. The user selected section is between the two black vertical lines. The orange sound blocks can be snapped to while scrubbing or can be ignored if fine scrubbing is desired.*

Conclusion and Future Work

- This database will assist in research for a number of diverse applications:
  - Child automatic speech recognition
  - Child speech science and linguistics
  - Human-robot interaction
- Going forward, we hope to generalize the methods for preliminary processing to all speech databases.

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[2] Yeung, G., & Alwan, A. (2018). On the Difficulties of Automatic Speech Recognition for Kindergarten-Aged Children. *Interspeech*, 1661–1665.

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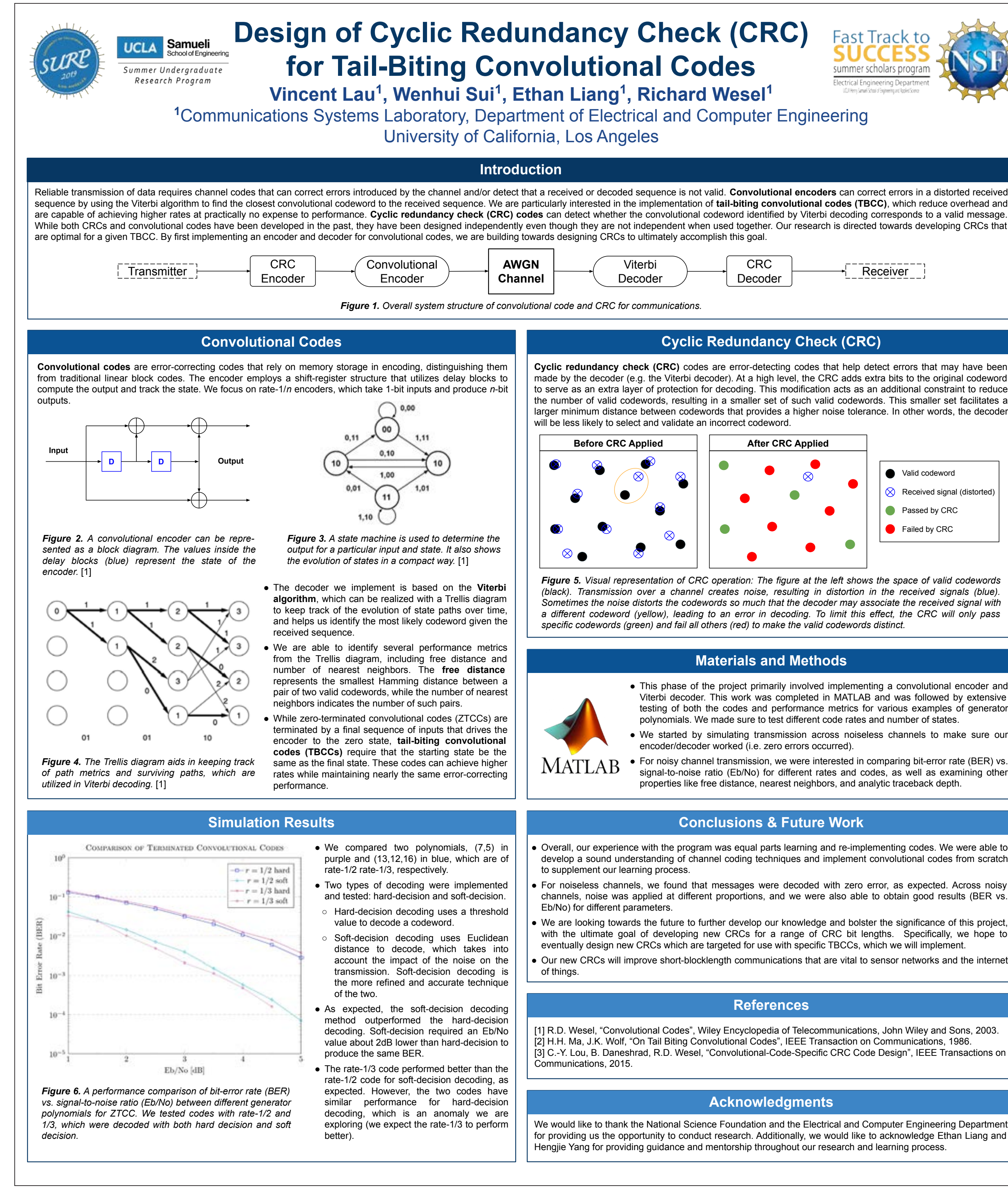
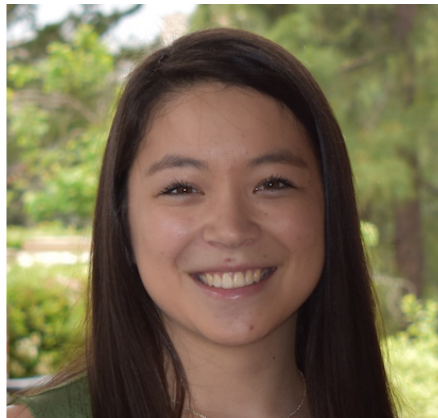
Design of Cyclic Redundancy Check (CRC) for Tail-Biting Convolutional Codes

Reliable transmission of data requires channel codes that can correct errors introduced by the channel and/or detect that a received or decoded sequence is not valid. Convolutional encoders can correct errors in a distorted received sequence by using the Viterbi algorithm to find the closest convolutional codeword to the received sequence. Cyclic redundancy check (CRC) codes can detect whether the convolutional codeword identified by Viterbi decoding corresponds to a valid message. While both CRCs and convolutional codes have been developed in the past, they have been designed independently even though they are not independent when used together. For zero-terminated convolutional codes (ZTCCs) that are terminated by a final sequence of inputs that drives the encoder to the zero state, our research group has designed CRCs that are optimal for a given ZTCC. Tail-biting convolutional codes (TBCCs) avoid the overhead caused by ZTCCs and therefore can achieve higher rates with essentially the same performance. Rather than using additional input symbols to drive the final state to zero, TBCCs enforce the constraint that the starting state is the same as the final state. Our research is directed towards developing CRCs that are optimal for a given TBCC.





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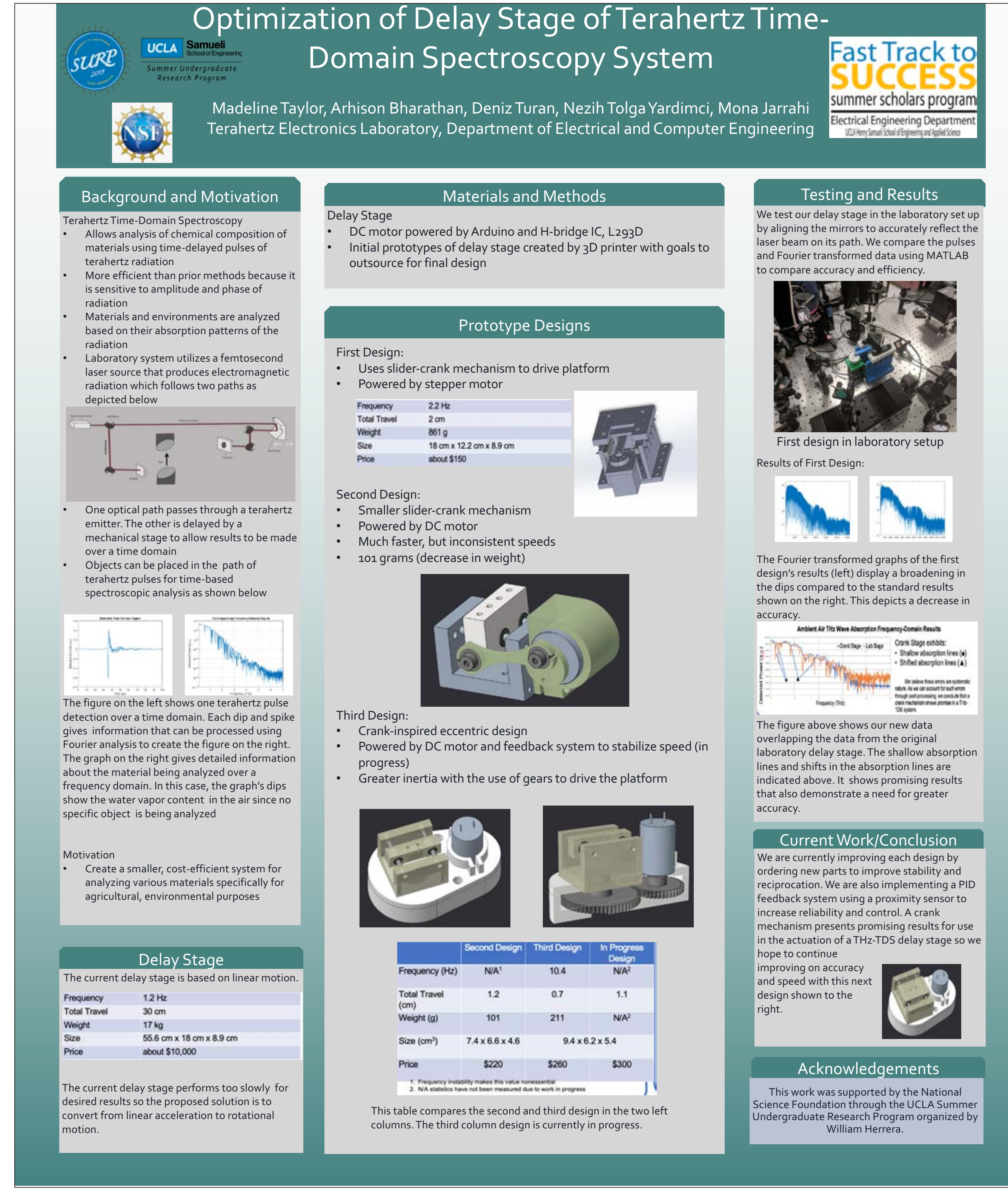
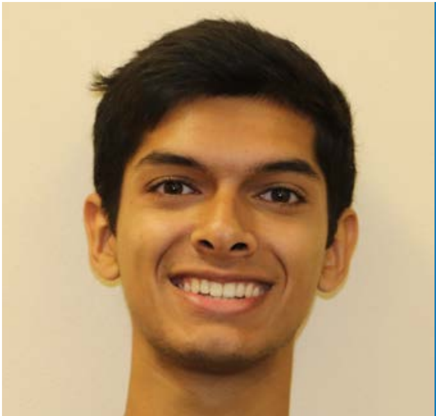
Optimization of Delay Stage of Terahertz Time-Domain Spectroscopy System

Terahertz time-domain spectroscopy (THz-TDS) allows us to analyze materials using pulses of terahertz radiation created by a femtosecond laser. Materials are analyzed based on their absorption patterns of the THz radiation. In the laboratory system, the detector receives pulses of THz radiation along with optical light pulses. The optical light path length is shifted by a delay stage which enables analysis of materials over a time domain and frequency domain.

Our goal is to miniaturize and improve the delay stage to convert the large laboratory system into a mobile, commercial device. The previous delay stage utilizes linear motion; a platform with mirrors accelerates back and forth to alter the path length of the radiation. Our main focus is designing a smaller prototype that relies on rotational acceleration to decrease the loss of speed from linear acceleration and deceleration.

Once a full prototype has been designed, it is tested in the laboratory setup and compared with previous data for accuracy. The frequency domain results of THz-TDS can be analyzed and used to determine chemical composition. When testing for accuracy, the Fourier graphs and THz pulses of our delay stage are directly compared with those of the laboratory stage. Our first test displayed broadening and shifting in the Fourier transformed waves which both indicate a worsened accuracy. However, the new delay stage works at almost double the frequency of the old one (2.2 Hz compared to 1.2 Hz) and only weighs 861 grams.





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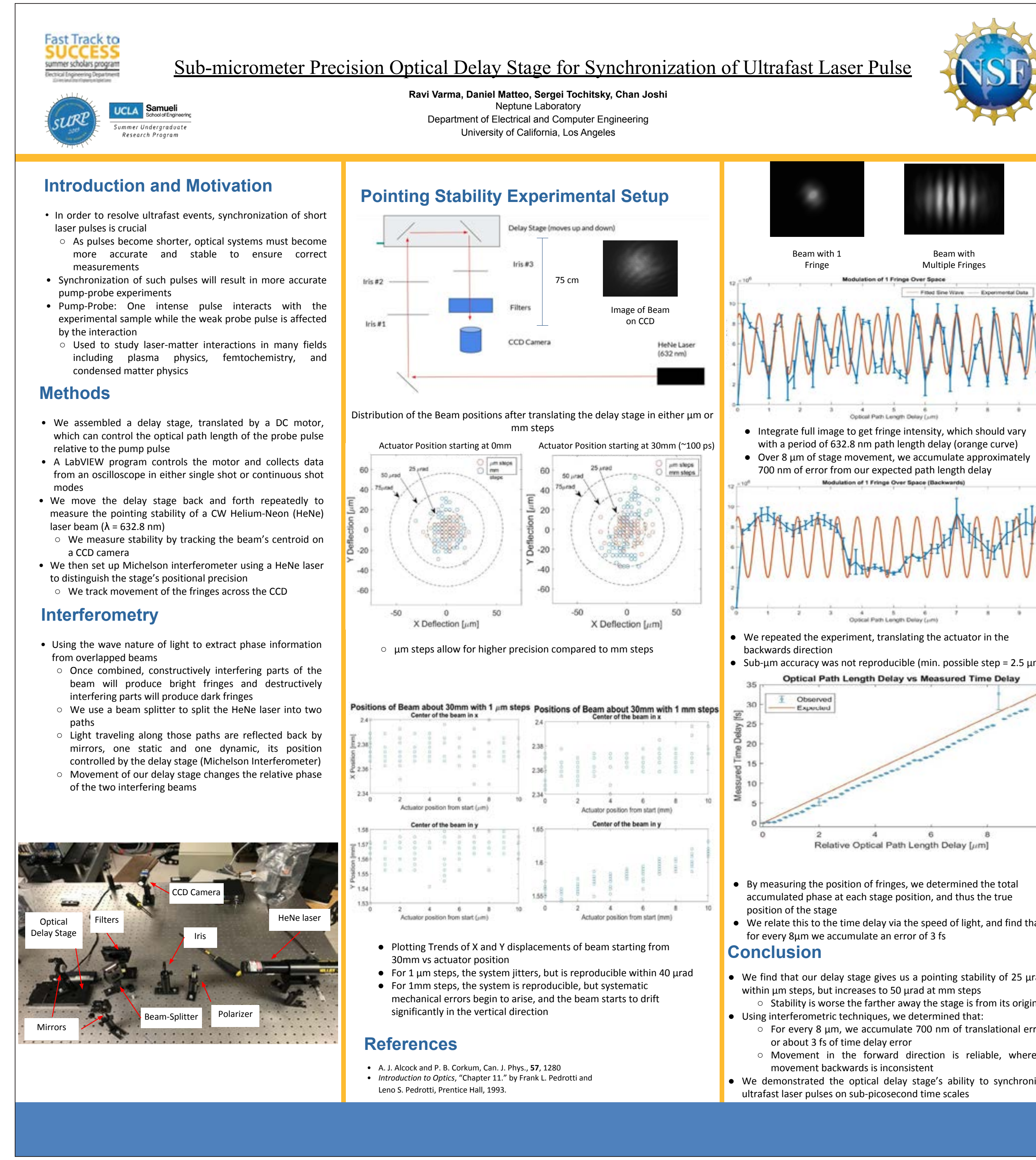
Sub-micrometer Precision Optical Delay Stage for Synchronization of Ultrafast Laser Pulse

As laser systems produce shorter and shorter pulses to push the limits of ultrafast and high field science, the requirements for precision timing and optical synchronization in the lab have increased accordingly. The coordination and control of the relative time delay between ultrafast pump and probe laser pulses is required to resolve short lived physical events. Time and space are intimately connected for light, and on picosecond and femtosecond time scales, errors and uncertainties in the optical path length on the order of micrometers and nanometers can drastically degrade the time resolution of measurements in the laboratory. We have implemented an optical delay stage powered by a DC servo motor and controlled by a LabVIEW program. To evaluate the accuracy of positioning two laser pulses, we study the stage's accuracy and repeatability in creating an optical path length delay with a HeNe laser Michelson interferometer. The pointing stability and reproducibility of the spatial beam profile after the stage is also determined. Understanding of the stage's precision will enable us to perform picosecond pump-probe experiments, or synchronize ultrafast laser pulses using cross-correlation.



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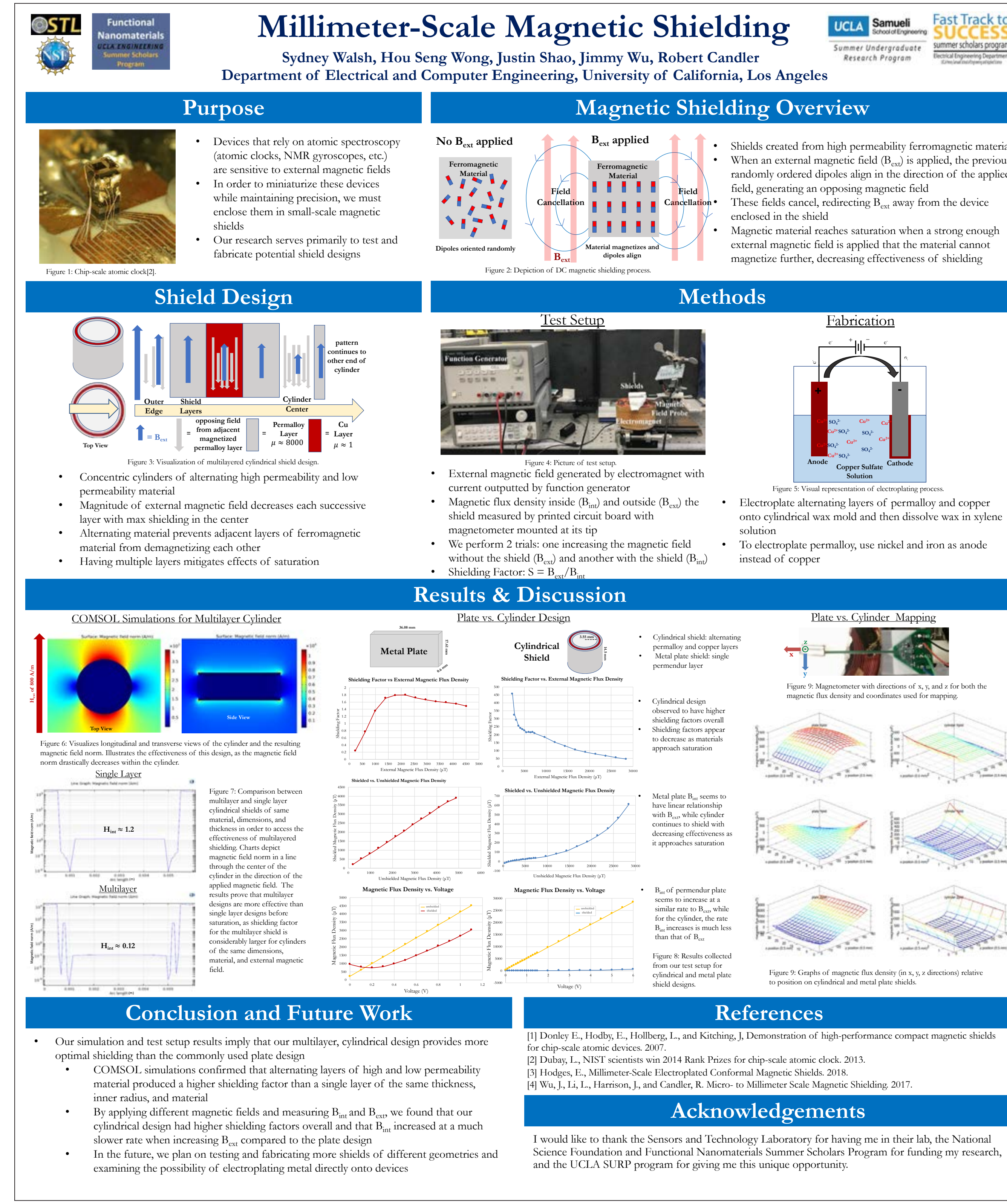
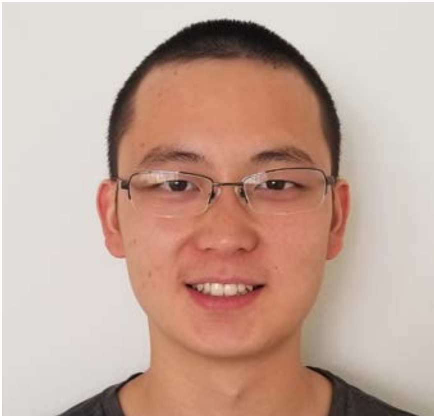
Millimeter-Scale Magnetic Shielding

Devices that rely on atomic spectroscopy, such as nuclear magnetic resonance gyroscopes and atomic clocks, are strongly affected by external magnetic fields. Thus, in order to miniaturize these devices while maintaining precision, small-scale magnetic shields must be developed to properly redirect magnetic field lines away from the enclosed devices. The purpose of our research is to fabricate and test potential shield designs. Based on previous research, we determined that the optimal design would consist of concentric cylinders of alternating high permeability and low permeability material. By alternating layers, we partially prevented adjacent ferromagnetic material from reducing the magnetization of that layer. Moreover, multilayer shielding allowed us to mitigate the effects of magnetic saturation, as a single layer of magnetic material would reach saturation more quickly, limiting the shield's ability to generate an opposing field. We conducted our research by simulating potential shield designs in COMSOL Multiphysics, developing an appropriate test setup to assess the effectiveness of our shields, and fabricating shields to test. For our test setup, we generated a magnetic field using an electromagnet and measured the magnetic flux density using a printed circuit board with a magnetometer mounted at its tip; shielding factor was determined by taking the ratio of external to internal magnetic field. Shields were fabricated by electroplating alternating layers of permalloy and copper.





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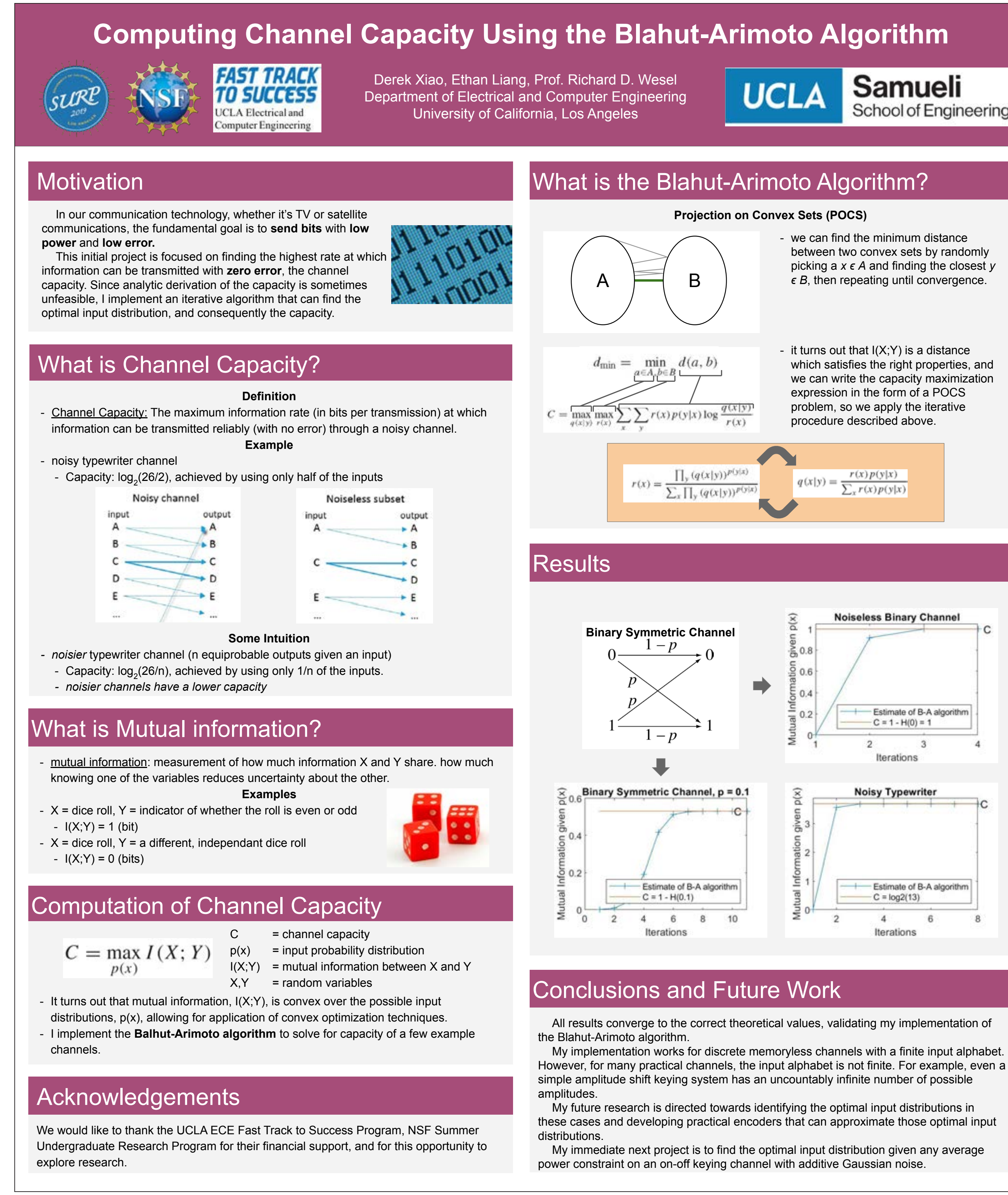
Computing Channel Capacity using the Blahut-Arimoto Algorithm

The maximum rate at which information can be reliably transmitted over a communication channel is the channel capacity, usually represented in units of bits per channel use. The ability to compute the capacity of any discrete memoryless channel based on its statistical description is a powerful and fundamental result of information theory. Broadly speaking, the noisier a channel, the lower its capacity.

Mathematically, the channel capacity is the maximum mutual information between the input and output of the channel, where the maximum is taken over possible input distributions. My research is focused on developing tools to identify the mutual-information-maximizing input distribution for a channel and consequently its capacity. As an initial project, I have implemented the Blahut-Arimoto algorithm, which finds the capacity-achieving distribution for any discrete memoryless channel with a finite input alphabet.

For many practical channels, the input alphabet is not finite. For example, even a simple amplitude shift keying system has an uncountably infinite number of possible amplitudes. Furthermore, there are practical communication systems where the optimal input distribution turns out to be asymmetric, such as on-off keying over an additive white Gaussian noise channel. My future research is directed towards identifying the optimal input distributions in these cases and developing practical encoders that can approximate those optimal input distributions.



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