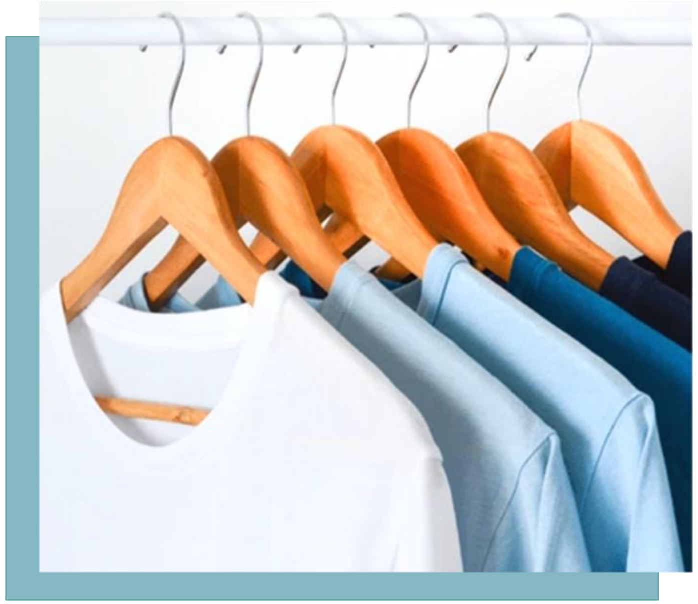


TEX-RAY

Special thanks to:

Testfabrics, Inc.
Your Source for Quality Materials

CHROMA®

Textile Identification via Raman Spectroscopy

Group 8

Our Team

Ariana Mihandoost

Photonic Science and Engineering

Danielle Samuels

Photonic Science and Engineering

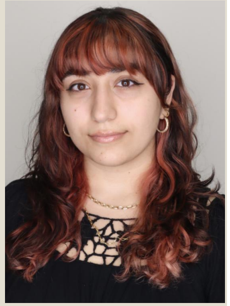
Austin Frost

Computer Engineering

Cameron Ricketts

Electrical Engineering

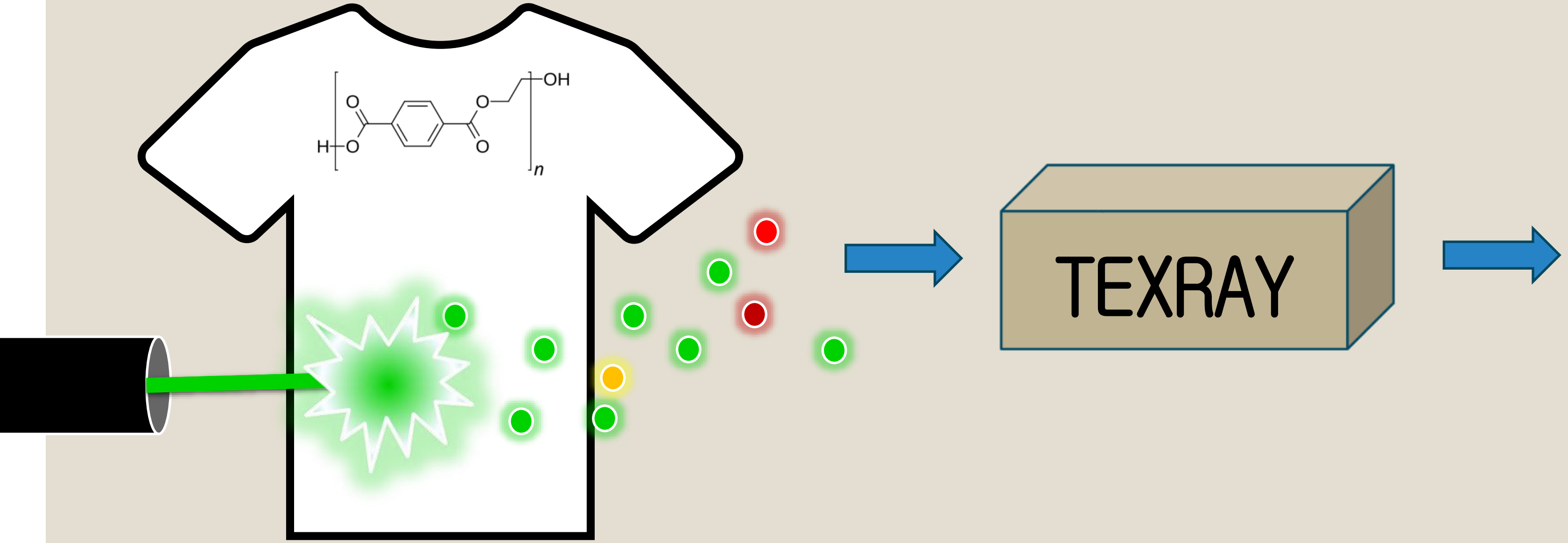
Motivation and Background

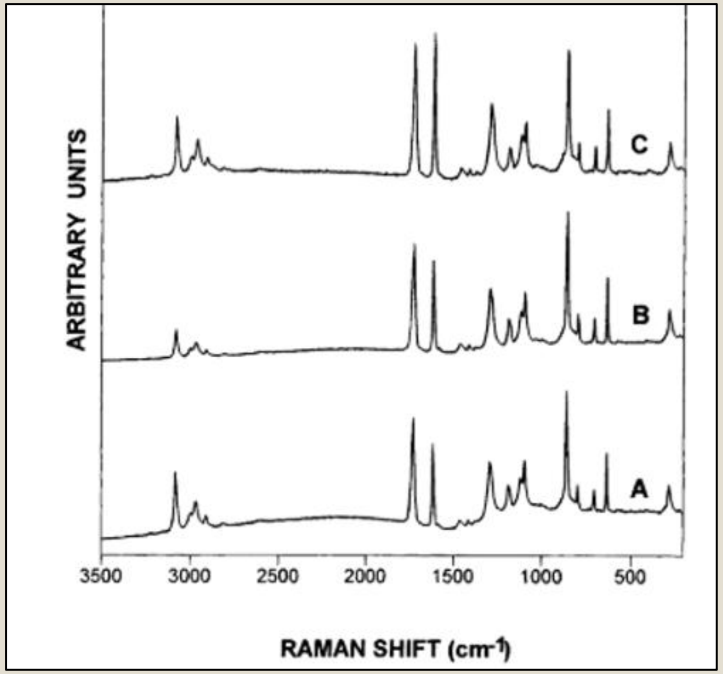


- Difficulty distinguishing counterfeit products
  - Easy to lie about fabric composition
  - Fake luxury goods almost identical to genuine articles
- Shifts in societal attitude
  - Preference for ethical consumption and environmentally friendly products
  - Clothing as long-term investment
  - Natural fibers are higher quality and more comfortable
- Consumer Rights
  - Buying expensive products, expecting to get the fabric you paid for
  - No affordable/convenient method of textile verification
  - Cheapest commercial product is $2,500

Raman Spectroscopy

- Molecules have distinct vibrational modes (vibration, rotation, stretching)
- The nature of these modes are uncovered from its Raman scattering
- The assessment of Raman scattering is therefore useful for nondestructive material identification





Core Goals

Basic Goals

Classify an undyed and unblended textile sample as either cotton or polyester based on spectral signature

Display results to user via LCD screen

Advanced Goals

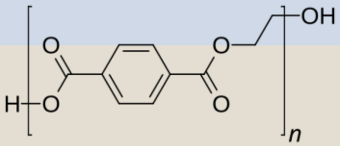
Conduct an accurate product comparison between two pieces of clothing to determine if they are spectrally similar

Classify two additional types of textile samples based on spectral signature

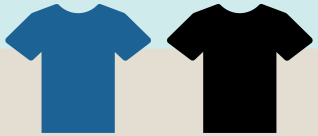
Stretch Goals

Integrate a mobile app to replace LCD screen functionality

Enable material analysis of dyed and/or blended fabric samples and display material ratios



✓Polyester



❌ Not a match

Core Objectives

Basic Objectives

Build an effective and cost-efficient spectrometer

Implement backscattering light collection configuration

Implement an efficient power source for the system to enable portability

Store reference spectra of cotton and polyester for comparison

Utilize dynamic time warping for highly accurate material analysis

Advanced Objectives

Create more robust fabric analysis software to include classification of nylon and wool

For product comparison: create a fabric analysis system to determine a unique clothing item’s spectral signature

Implement a data processing algorithm to determine the correlation between a sample clothing product and a stored reference item to find a match

Stretch Objectives

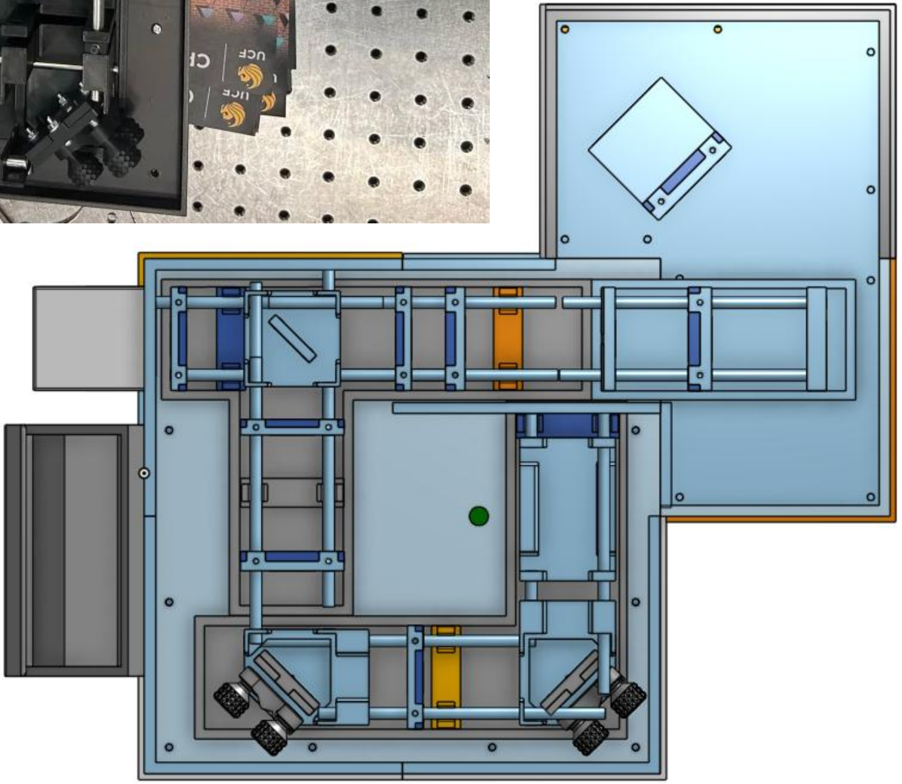
Determine a method utilizing machine learning to find the material ratio of blended fabrics

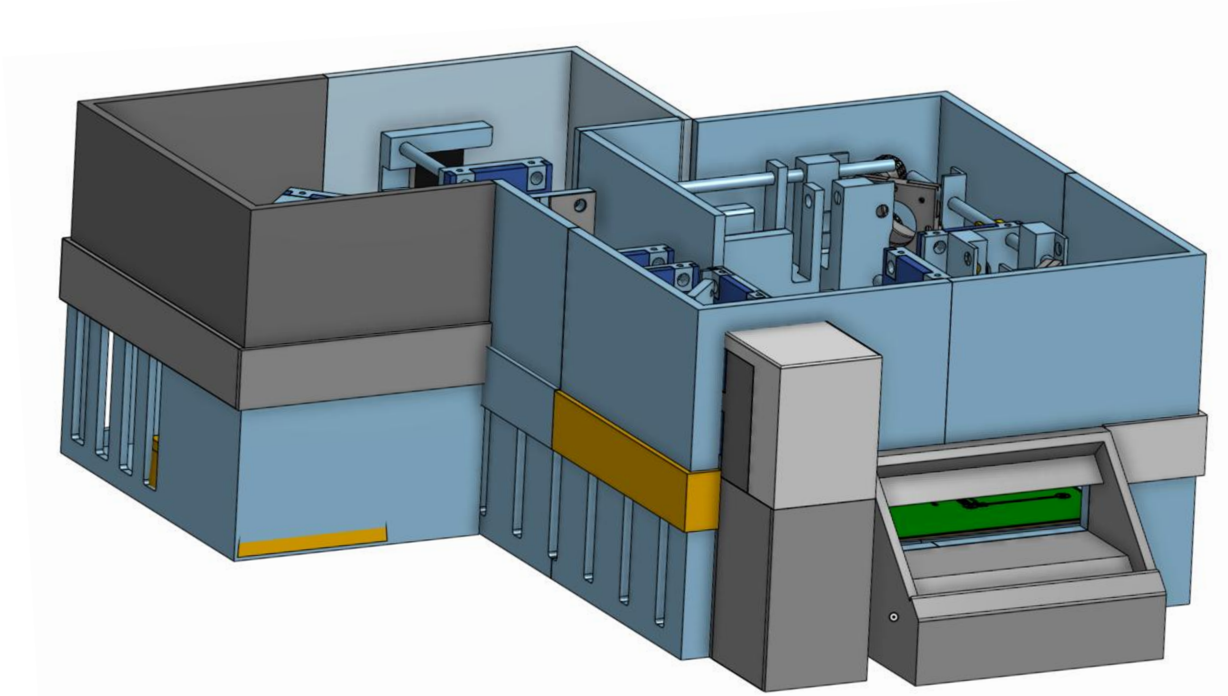
Determine a method of separating and identifying spectral signatures of dyes from fabrics to superimpose onto fabric results

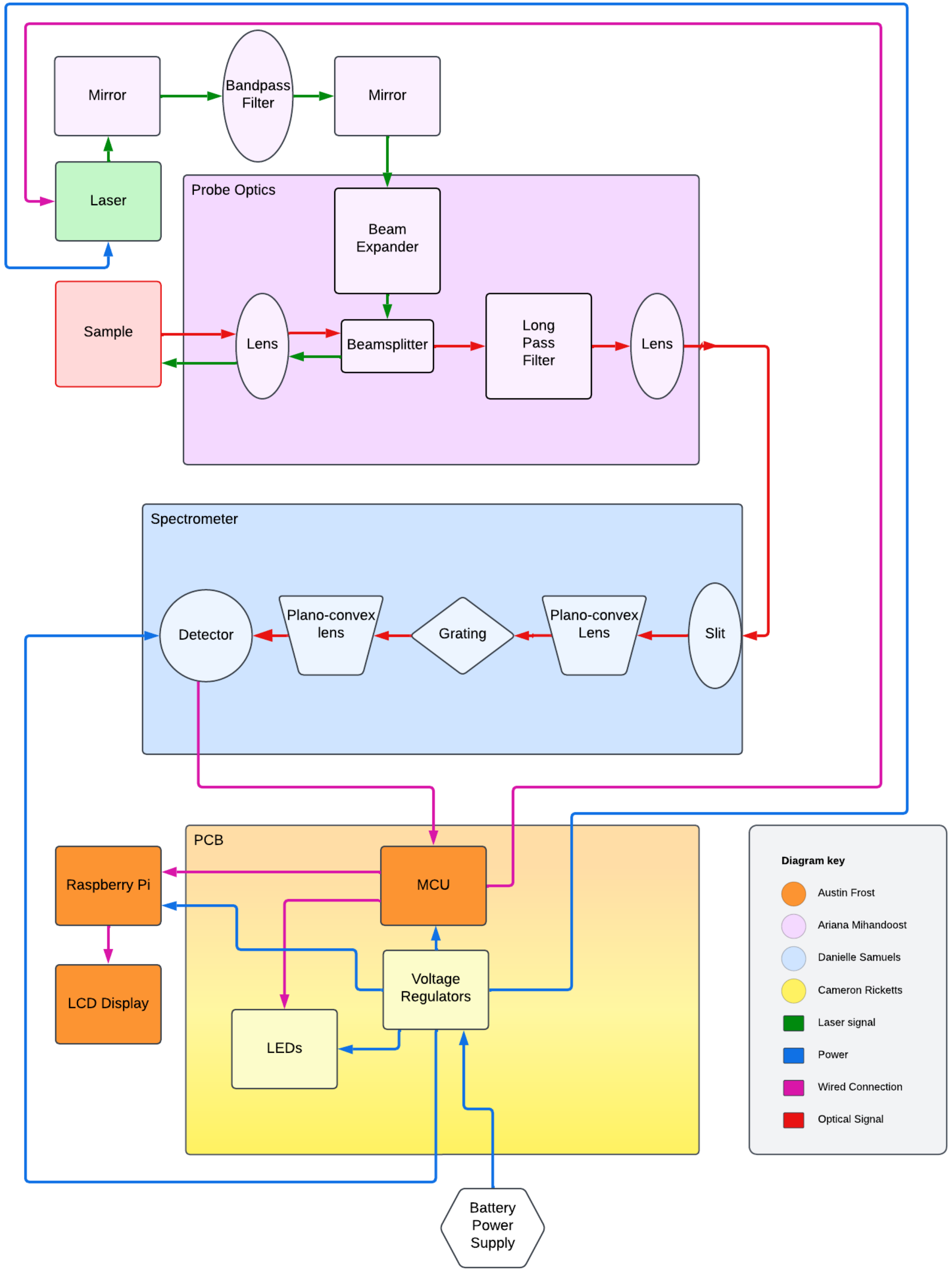
Engineering Requirements

Parameter	Specification	Units
Material Analysis Accuracy	>90%	Percent
Total Response Time	<15	Seconds
Product Comparison Accuracy	>90%	Percent
Spectral Resolution	<30	cm^{-1}
Spectral Range	800 – 3100	cm^{-1}
Signal Strength	>1	pW
Battery Life	>2	Hours
Regulated Voltage	3.3 - 5	Volts
Power Consumption	<35	W
Battery Energy	>=72	Wh
Regulated Current	1	Amps
Unit Size	<24’’x18’’	Inches
Unit Weight	<10	lbs
Cost	<$2,500	USD

OVERALL SYSTEM DESIGN

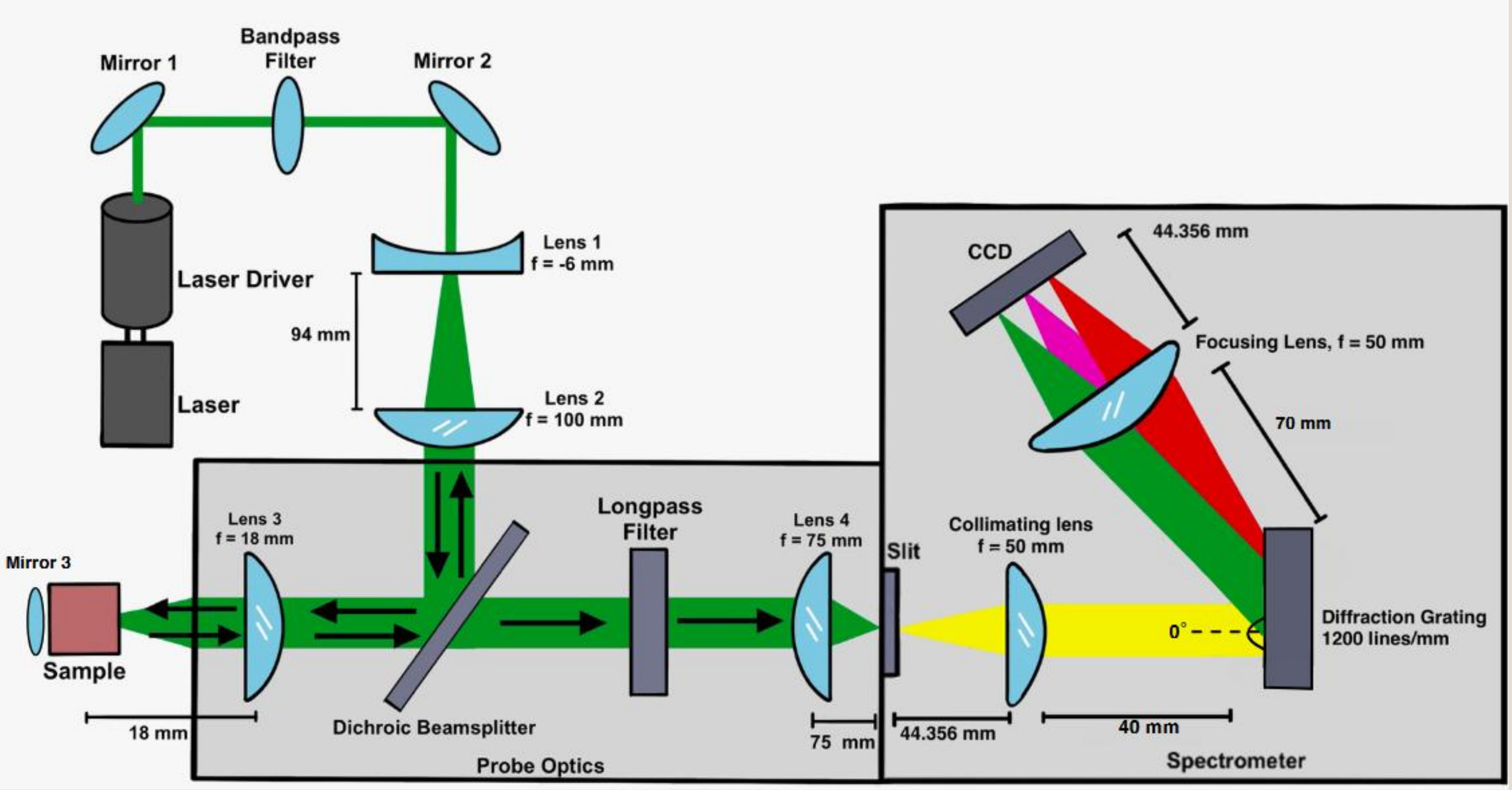


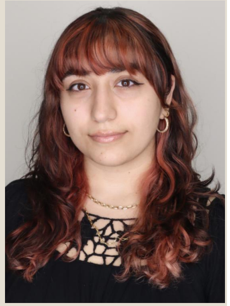




HARDWARE BLOCK DIAGRAM

Optical Schematic





Wavelength and Laser Selection

Blue vs. Green:

- 473 nm expensive and hard to find
- 450 nm pushes the risk of uncontrollable fluorescence
- 532/520 nm proven suitable for our fabric samples

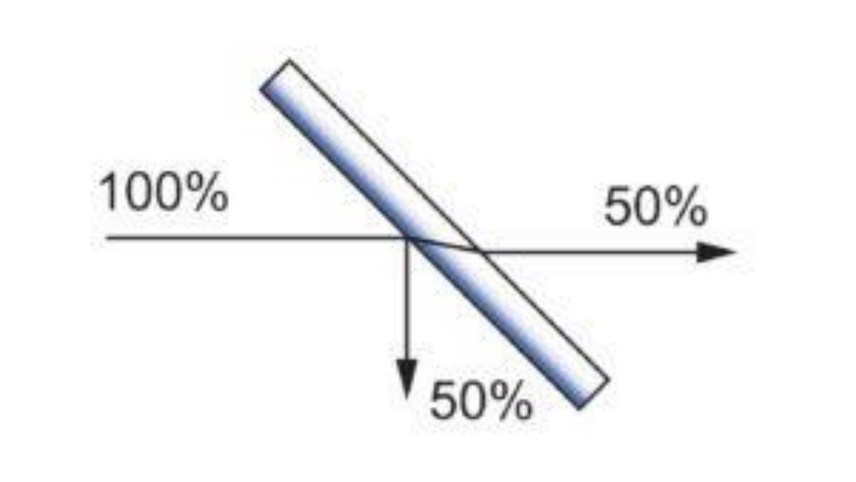
Q-Baihe laser module:

- Module eliminates need for collimating lens
  - Minimal beam divergence
- 40 mW output power sufficient for Raman signal generation
- Very narrow spectral linewidth
- Cheapest of all options

Specification		Thorlabs DJ532-40	ams-OSRAM PL 520B	Q-BAIHE 532 nm module	Thorlabs L450G3	Civil Laser GH04580 A2G
Peak Wavelength		532	520	532	450	450
Output Power (mW)		40	80	40	100	80
Operating Current (mA)		330	200	500	80	110
Threshold Current (mA)		160	40	N/A	12	22
Operating Voltage (V)		1.9	6	12	5.2	5.3
Beam Divergence	Parallel	.69°	6.3°	<1 mrad	8.4°	10°
	Perp.	.69°	22.5°	<1 mrad	21.5°	24°
Spectral Linewidth		.0283 pm	1 nm	1 nm	1.25 nm	N/A
Price		$212.64	$46.00	$43.98	$138.57	$9 (min. 10 purchase)

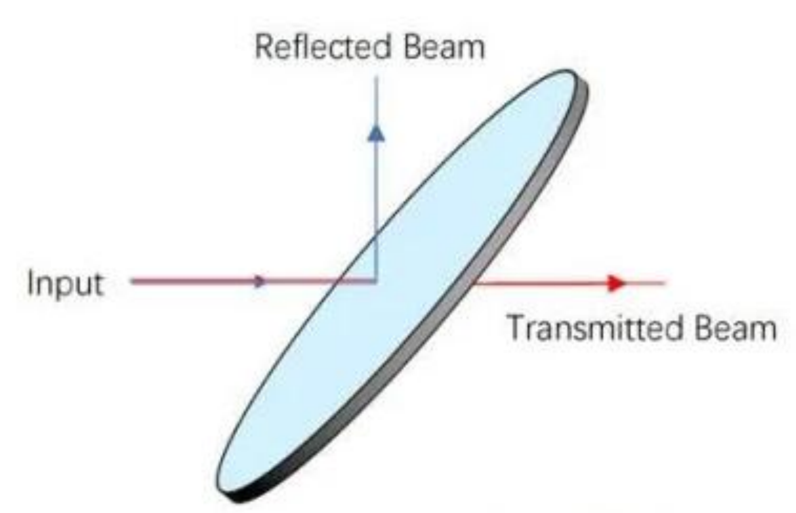
Beamsplitting Technology Comparison

50/50 Beamsplitter



- Reduces laser power incident on sample by 50%, limiting signal generation
- Reduces collection of back-scattered signal by 50%
- Allows laser line and Rayleigh scattering to pass through with the Raman signal

Dichroic Mirror



- Selectively reflects light below a certain wavelength
- Enables full reflection of laser line onto sample
- Prevents significant amount of Rayleigh scattered and laser light from transmitting

Dichroic Mirror Selection

The ideal dichroic must:

- Completely reflect 532 nm light
- Minimize reflection above 532 nm
- Have high % maximum transmission
- Have a large diameter
- Be as cheap as possible

Chroma T550lpxr:

- Relatively budget friendly
- Fully reflects laser line, maximizing intensity at the sample
- OD4 blocking until 538 nm
- Large diameter and high transmittance
- Limits spectral range to 800 cm^{-1}

	MKS Newport DCM13	Chroma T550lpxr	Chroma RT532rdc	Edmund Optics #86-393 / #86-386	Thorlabs DMLP550 / DMLP550T
Cut-on wavelength (nm)	552	550	536	552	550
Transmission wavelength (nm)	561.4 - 790	550 - 1000	536 - 1000	561.4 - 790	565 - 800
Reflection Wavelength (nm)	514.5-543.5	390 - 540	390 - 532	514.5- 543.5	380 - 533
Diameter (mm)	25	25	25	25 / 12.5	25.4 / 12.7
Thickness (mm)	3.5	1	3	3.5	3
Reflectance	>98%	>97%	>97%	>98%	>90%
Transmittance	>95%	>96%	95.97%	>95%	>85%
Angle of Incidence	45°	45°	45°	45°	45°
Clear aperture diameter (mm)	22	22.5	22.5	21.33 / 8.8	>22.9 / > 11.4
Cost	$359	$250	$600	$280 / $202	$200.76 / $134.24

Filter Technology Comparison and Selection

Notch Filter	Longpass Filter
Band-reject filter, only blocks the laser line	Edge filter, reject all light below cut-on wavelength
Large transition width between stopband and passband	Steeper transition widths, minimizing Raman signal loss
Wavelength tunable	Available in large variety of wavelengths

	Semrock BLP01-532R-25	Chroma ET542lp	Chroma RET537lp	Edmund Optics #29-191	MKS Newport 10CGA-530
Cut-on wavelength (nm)	541	542	537	550 ± 1	550 ± 5
Rejection wavelength (nm)	270 - 532	300 - 540	300 - 536	200 - 539	N/A
Transmission wavelength (nm)	546.9 - 900	555 - 1000	540 - 1100	560 -1650	N/A
Transmission (%)	> 93	> 98	> 98	> 91	> 90
Optical density OD (average)	> 6	6	> 6	> 4	> 5
Diameter (mm)	25	25	25	12.5 ± .2	25.4
Clear Aperture (mm)	>22	22.5	22.5	> 10	> 22.86
Cost	$409.00	$365.00	$600.00	$199.28	$47.00

Chroma ET542lp:

- OD6 blocking until 539 nm
  - Limits spectral range to 244 cm^{-1}, meaning the dichroic is the main limiting factor
- 98% transmission at 544 nm
- Large clear aperture to collect more Raman signal
- Balances performance with budget

Diffraction Grating Selection

Ruled	Holographic
Diffraction efficiency is defined by blaze wavelength and angle, and is higher for higher groove densities	Lower diffraction efficiency for greater groove densities
Irregularities in rulings can result in stray light	Holographic manufacturing practices limit stray light
More cost efficient	More costly

Resolving Power $R = \frac{\lambda}{\Delta\lambda} = mN$

$$\frac{595\ nm}{\Delta\lambda} = 1200\ \frac{grooves}{mm} * 25\ mm$$

$\Delta\lambda$ = 0.01983

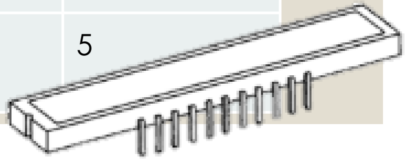
	Thorlabs GR25-1205	MKS Newport 33025FL01-280R	Edmund Optics 43-751	MKS Newport 3025FL01-266R
Groove density (grooves/mm)	1200	1200	1200	900
Blaze Wavelength	500 nm	500 nm	500 nm	550 nm
Blaze angle	17° 27'	17.5°	17.45°	14.3°
Efficiency	~90%	~ 95%	~85%	~90%
Size (mm)	25 x 25	12.5 x 12.5	12.7 x 12.7	12.5 x 12.5
Price	$128	$94	$81	$155

Detector Selection

CCD	CMOS
Higher sensitivity towards low Raman signal	Increased noise in low signal conditions
Higher QE (standard BI ~ 90%)	Lower QE (standard ~45%)
Consumer CCDs are well established in Raman spectrometer systems	Specialized, sCMOS sensors can be implemented

- Large detector width
- Small pixel size
- High QE in our desired region at room temperature
- Adequate dynamic range
- Low power consumption

	SONY CCD IXL511	TOSHIBA CCD TCD1304DG	TOSHIBA CCD TCD2717BFG	TOSHIBA TCD1209DG	HAMATSU S14660-1024
Pixels	2048	3648	7500	2048	1024
Pixel size (µm)	14 x 200	8 × 200	4.7 x 4.7	14 x 14	14 x 14
Total Detector Width (mm)	28.6	29.1	53.3	28.6	14.3
Spectral Response	70-90%	~100%	90-100%	N/A	~75%
Package/ Case	22 pin DP	22 pin CERDIP	32 pin CLCC	22 pin CERDIP	24 pin ceramic DIP
Operating temperature	-10 to 60℃	-25 to 60℃	0 to 60℃	-25 to 60℃	-50 to 50℃
Dark Current	3 to 6 mV	2 to 5 mV	1 to 6 mV	1 to 2.5 mV	50 - 500 (e-/ pixel/s)
Dynamic Range	267	300	N/A	2000	3330 - 6660
Data Rate (MHz)	2 (Max)	2	0.5 to 1 (35 Max)	1	0.5
Power Supply Voltage (V)	5	3 (min)	10	12	5



Spectrometer Design

Desired spectral range: 800 – 3100 cm^{-1} (550 – 640 nm)
Desired Spectral Resolution: <30 cm^{-1} (1 nm)

Diffraction Grating Equation

$m\lambda = d(sin\alpha + sin\beta)$ $\alpha = 0° \rightarrow \beta = 45.56°$

Reciprocal Linear Dispersion

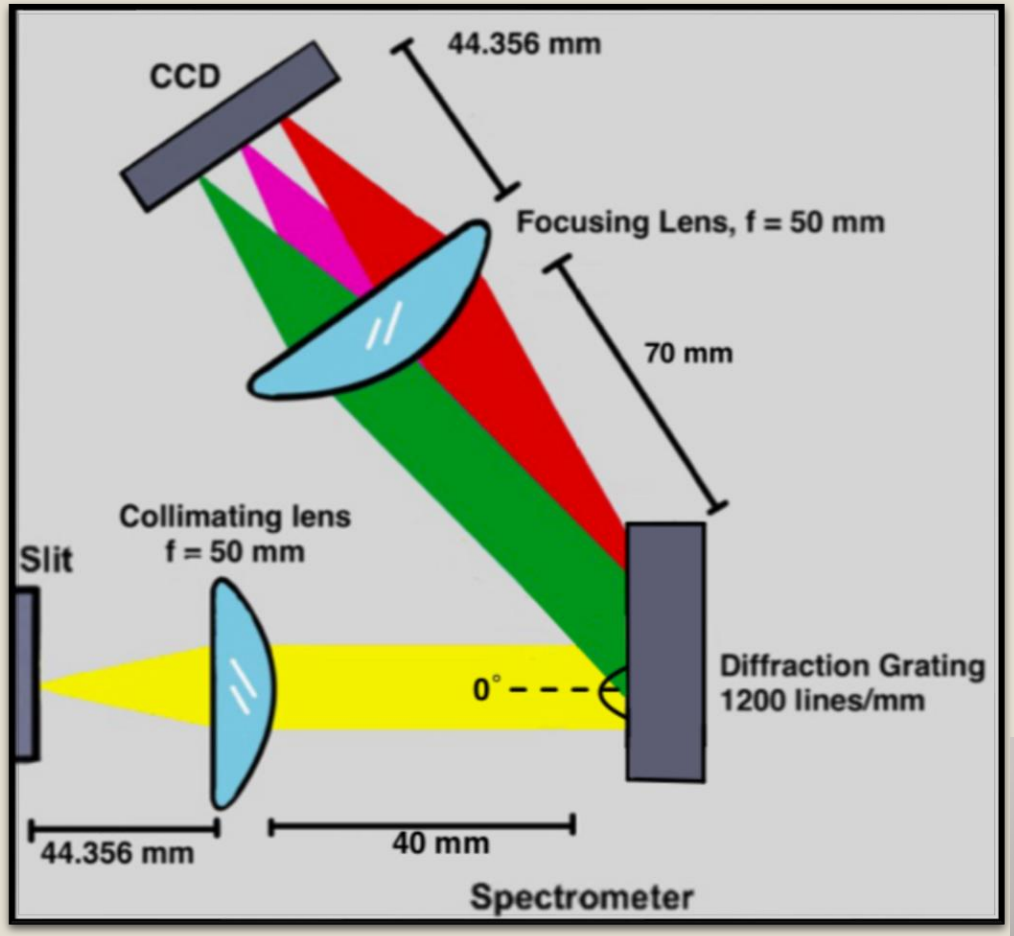
$$\frac{dv}{dl} = \frac{\mathrm{d}\cos(\beta)\left(v_0 - v_j\right)^2}{\mathrm{m}M_F} = 329.612\ cm^{-1}$$

Resolution

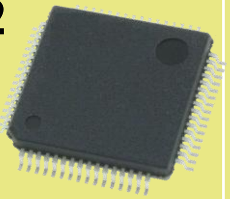
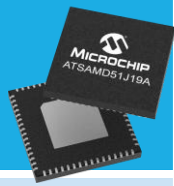
$$dv = \left(\frac{dv}{dl}\right) * Wp = 16.64\ cm^{-1}$$

Spectral Range

$$\mathrm{x} = v_0 - v_j - \left[\left(v_0 - v_j\right)^{-1} + \frac{dWd}{\mathrm{m}M_F}\right]^{-1} = 8756\ cm^{-1}$$



Microcontroller Unit Selection

	STM32 	**ESP32** 	**ATSAMD51J19A** 	**NPX i.MX RT1060** 
Clock Speed	84 MHz	240 MHz	120 MHz	600 MHz
ADC Resolution	12	12	12	10
ADC Mega Samples Per Second (MSPS)	2.4	2*	1	1
Price	$6.42	$1.85	$5.54	$11.16

STM32

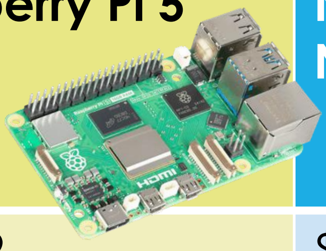
- **Higher Level of Timer Configuration**
- **84 MHz ADC Clock Speed Limit**

ESP32

- **Lower Cost**
- **Higher Clock Speed**

***ADC Sampling Rate Is Much Lower In Practice**

Single-Board Computer Selection

	Raspberry Pi 5 	**NVIDIA Jetson Nano** 	**Coral Development Board** 
Price	$69.49	$88.99	$169.99
Floating Point Operations Per Second	32 G	472 G	4 T
RAM	4 GB	4 GB	1 GB
Product Support	High	Moderate	Moderate
Community Support	Very High	Low	Low

Raspberry Pi

- **Higher Community & First Party Support**
- **Lower Price**

LCD Selection

	Hosyond Raspberry Pi Display 	DIYmall ESP32 Display 
Price	$32.99	$19.99
Size (Inches)	6.02 x 5.63	4.72 x 3.19
Resolution (Pixels)	800x480	240x320
Supply Voltage	3.3 V	5 V
Communication Method	DSI	USB

Hosyond Display

- **Raspberry Pi Compatible**
- **Higher Resolution**
- **Higher Refresh Rate**

Power Distribution

	Voltage	Current	Power
ESP32	3.0V – 3.6 V	80mA	24 mW – 288mW
Laser	~12V	~250mA	~3W
Raspberry Pi 5	5.0V – 6.0 V	3A – 5A	15W – 30W
STM32	1.7V – 3.6V	6mA – 32mA	10mW – 1152mW
TCD1304Dg	3.0V – 5.5V	6mA – 19mA	18mW – 105mW
Hosyand 5 inch Display	~5V	250mA – 800mA	1.25W – 4W

Power Source Selection

	Battery (DC)	AC	Solar Power (DC)
Current type	Direct Current	Alternating Current	Direct Current
Portability	High (size and weight dependent)	Low (stationary)	Moderate (mostly stationary with exception of some portable panels)
Power Storage	Chemical energy stored	None (continuous supply)	Can store in batteries
Reliability	Great at short distances; depletion may impact	Great	Varies heavily
Ease of Use	Simple	Requires at least one outlet	complex
Stability	Very stable and constant	Fluctuates do to alternating current	Stable as DC, light intensity may cause fluctuations
Efficiency	Moderate	High	Lower
Cost	Low to moderate	Low	High
Maintenance	Medium	Low	Medium
Uses	Portable sensitive electronic devices	Stationary high demand loads	Hybrid systems

- Portability: Batteries offer high portability, making them ideal for mobile and remote applications.
- Stable Power Output: They provide a very stable and constant DC output, which is suitable for sensitive electronics.
- Ease of Use: Batteries are simple to use with no need for outlets or complex setups.
- Moderate Maintenance: Does not require much effort to maintain outside of charging/replacing

Battery Selection

	Lithium-Ion	Lithium Iron Phosphate	Sealed Lead Acid
Energy Density	High	Moderate	Low
Portability	Excellent	Good	Poor
Charge Cycle Lifespan	2000-5000 cycles	2000-5000 cycles	300-500 cycles
Charge Retention	1-2% loss per month	2-3% loss per month	Excellent
Capacity	3.5 Ah	6 Ah	7 Ah
Maximum Discharge Current	4.2 A	5 A	70 A
Maximum Power Output	46.6 W	76.8 W	840 W
Cost	$90	$53	$16
Weight	0.15 kg	0.75 kg	1.91 kg
Safety	Moderate	High	High

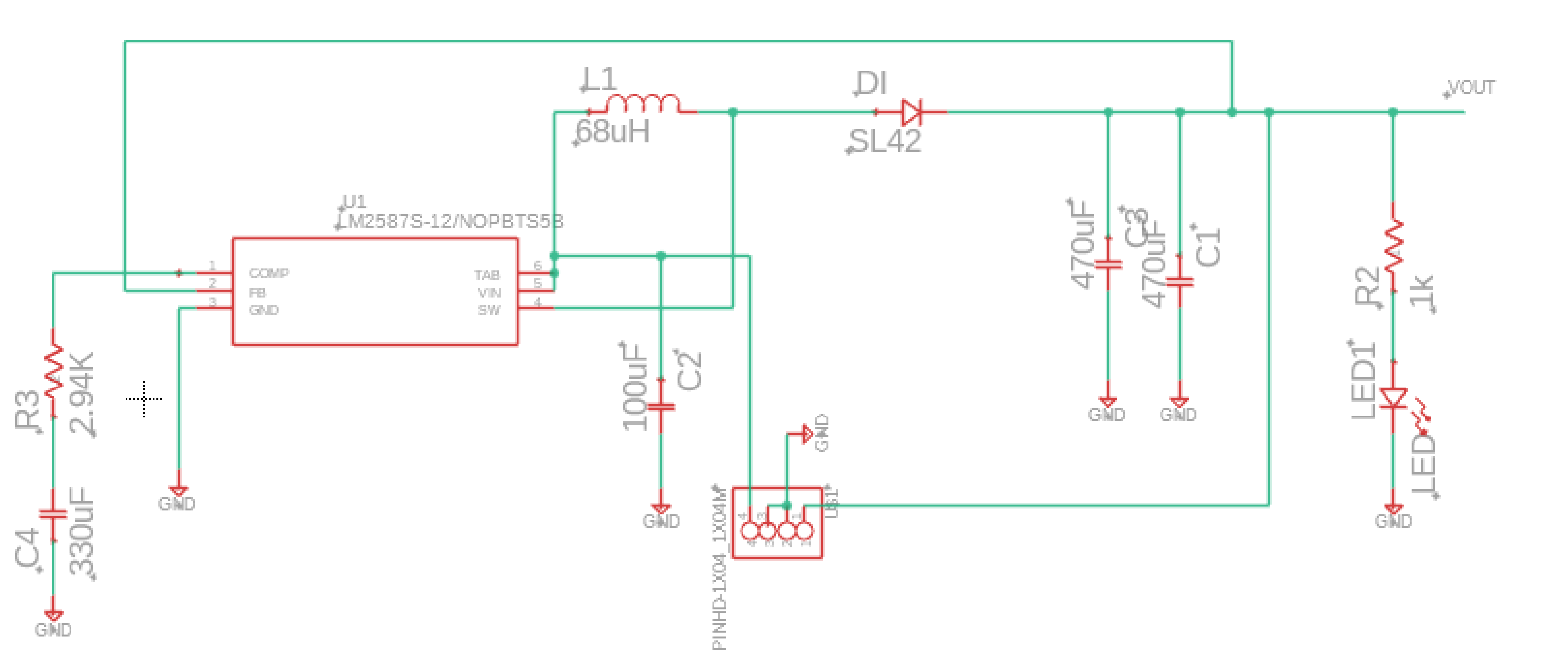
- Minimal Safety Concerns
- Reliable Output
- Sufficient Current for the system, outputting up to 5A
- Lightweight

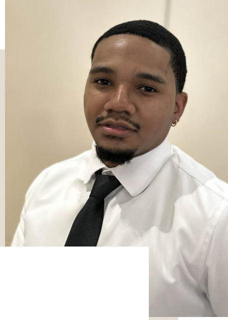
Voltage Regulator Selections

	12V	5.4 Volt	3.3 Volt
Part Number	LM2587S	LM22679-ADJ	LM2576
Topology	Boost	Buck	Buck
Output Voltage	~12 Volts	Adjustable Using Feedback Resistors	~3.3 Volts
Max Input	~40 Volts Max	~42 Volts Max	~40 Volts Max
Type	Switching	Switching	Switching
Output Current	Up to 5 A	Up to 5 A	Up to 3 A

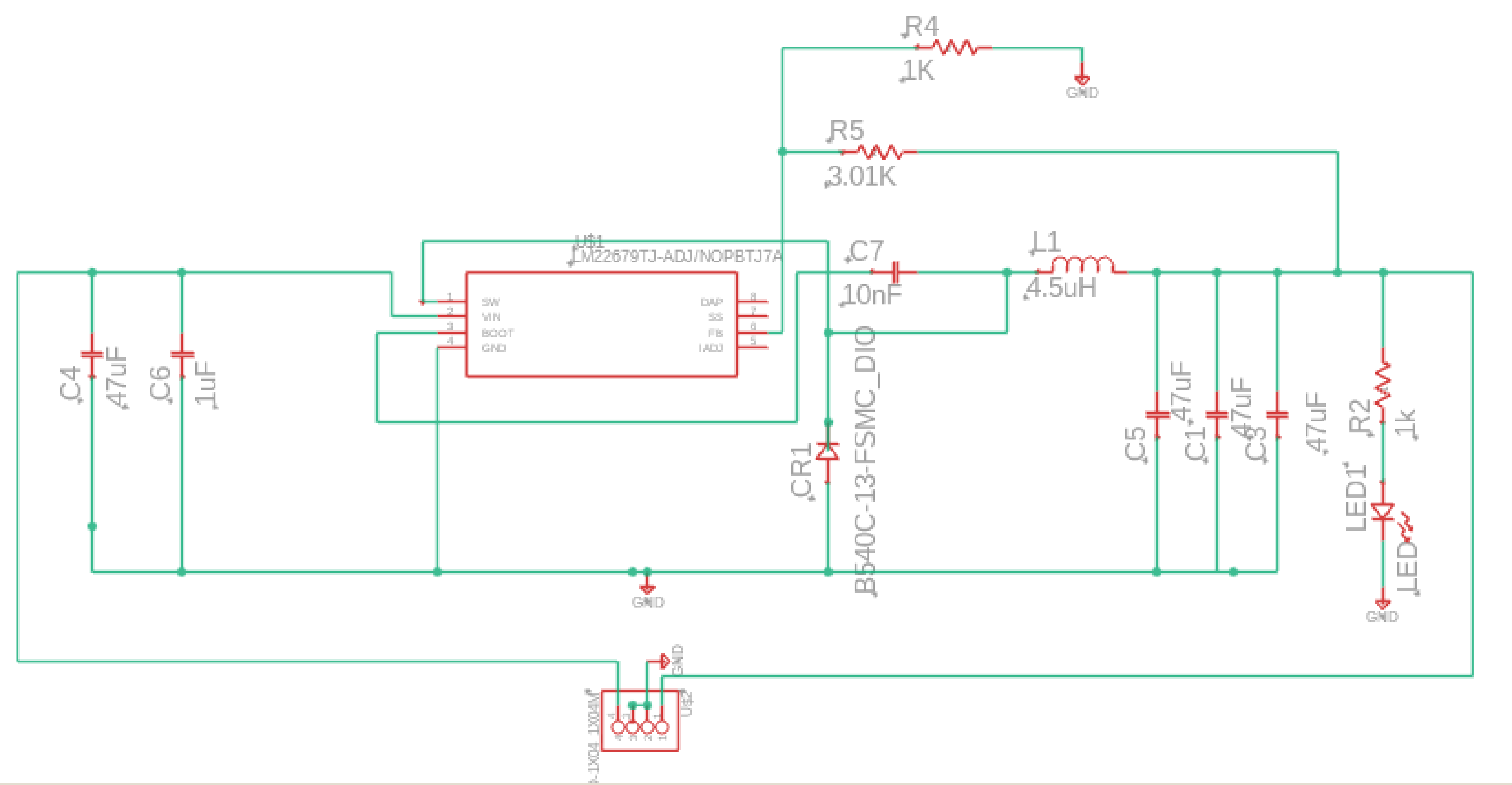
- Gives appropriate voltage outputs for the components being used
- Efficiently power the system without contributing to power loss
- Low heat production
- Able to supply ample current

12 Volt Regulator schematic

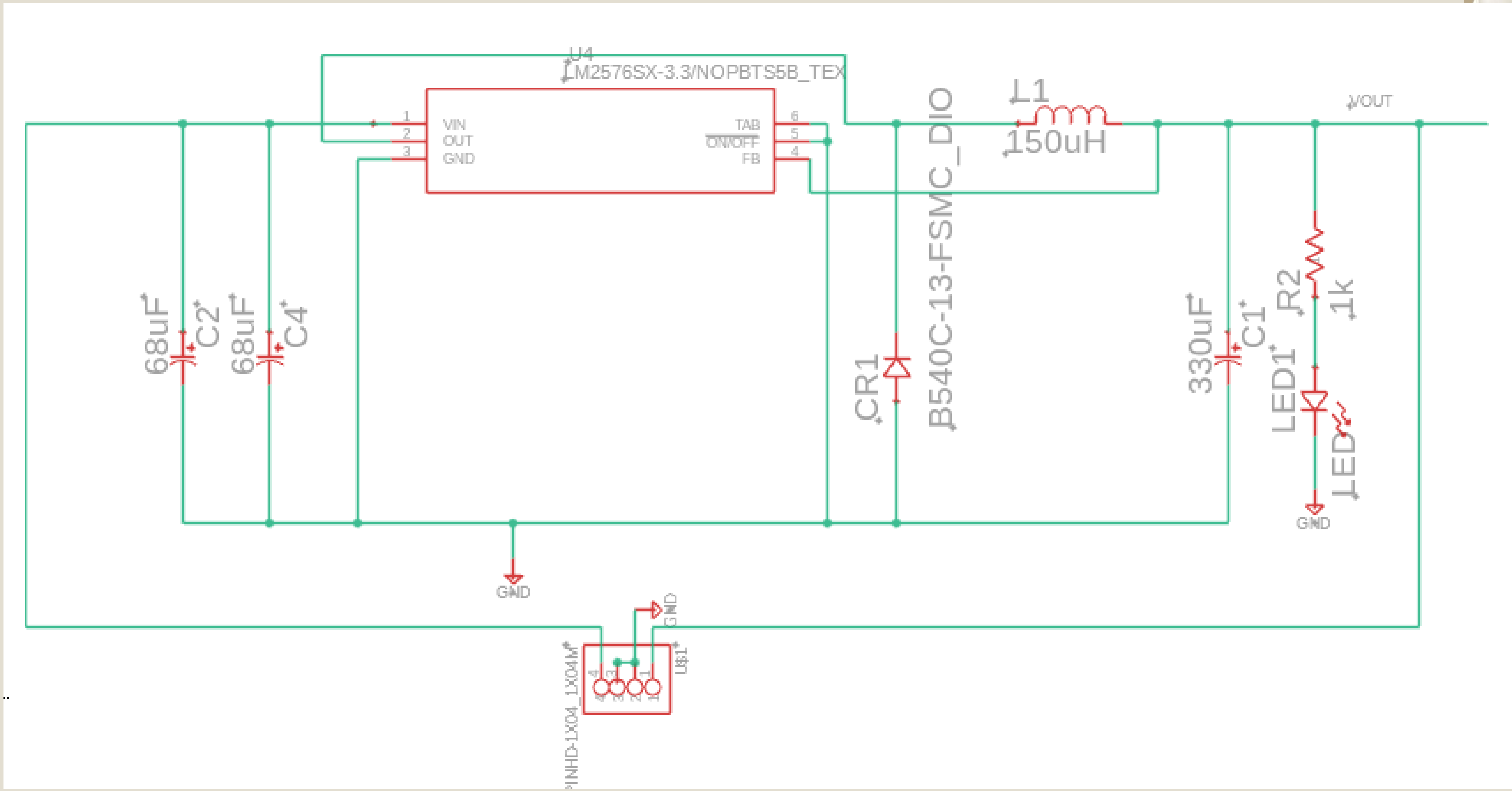




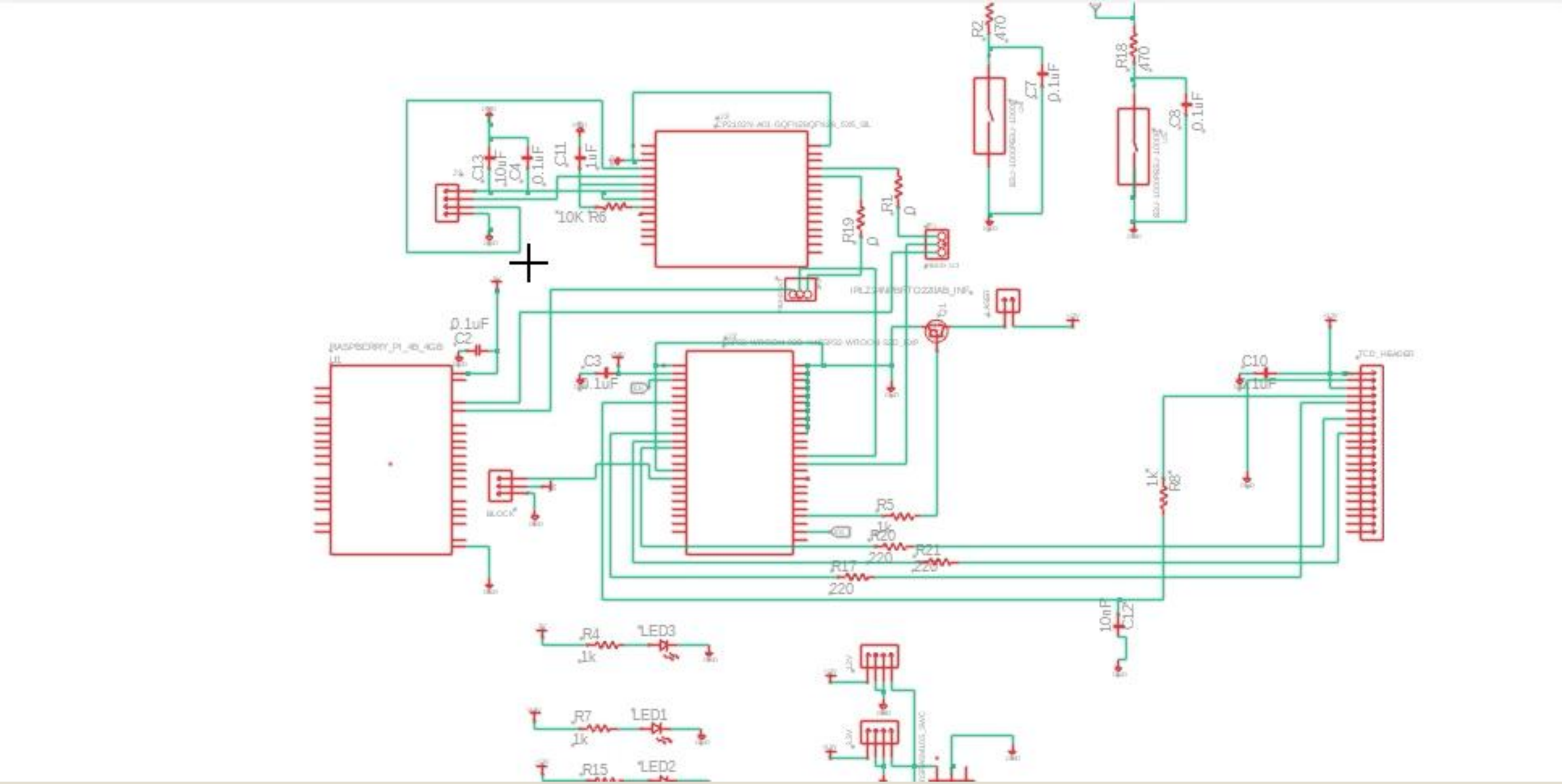
5 Volt Regulator Schematic



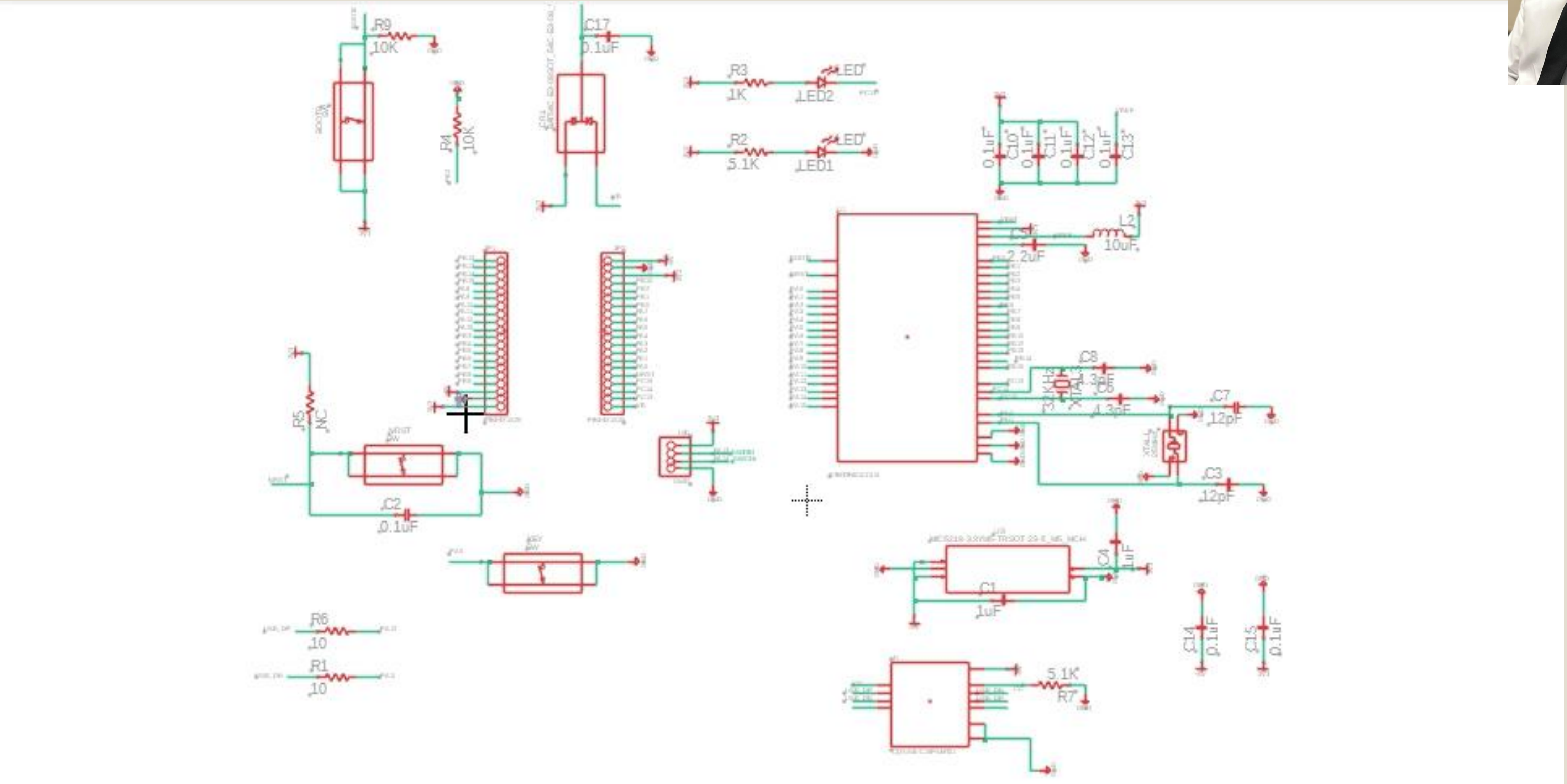
3.3 Volt Regulator Schematic



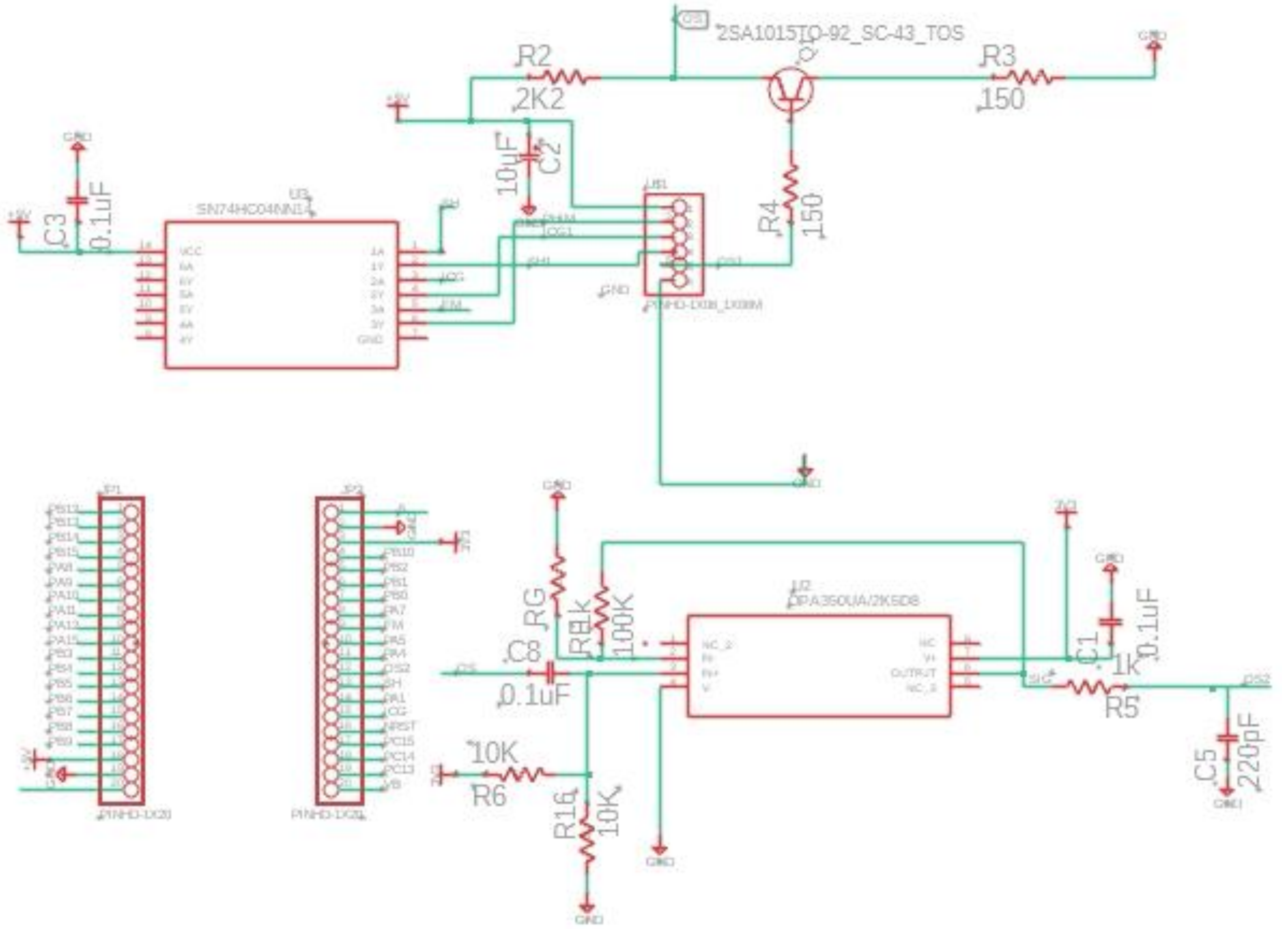
Main Board Schematic



STM32 Dev Board



Signal Amplifying Board



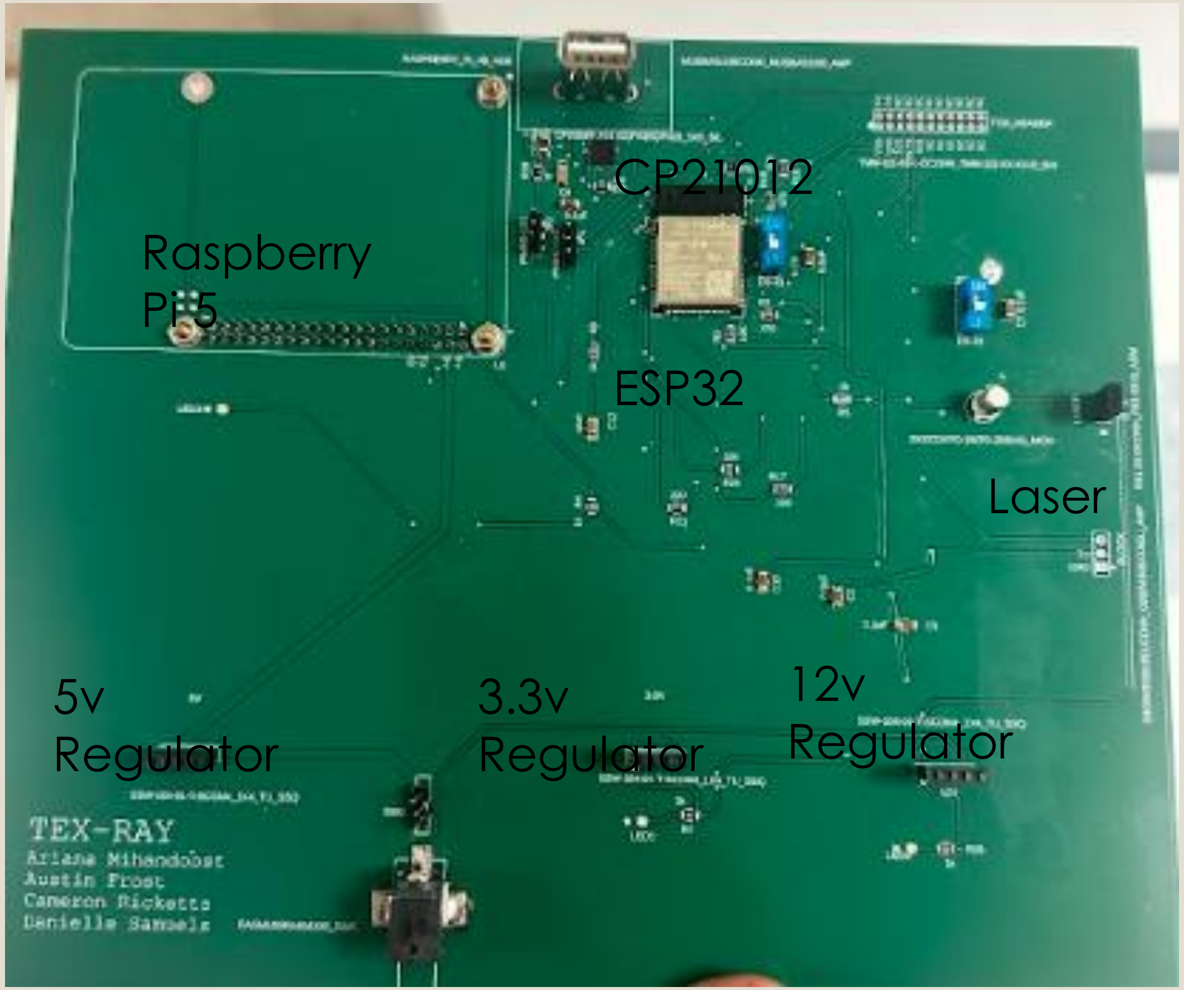
Voltage Supply PCBs

Power Raspberry Pi 5 and its peripherals (LCD display and STM32)

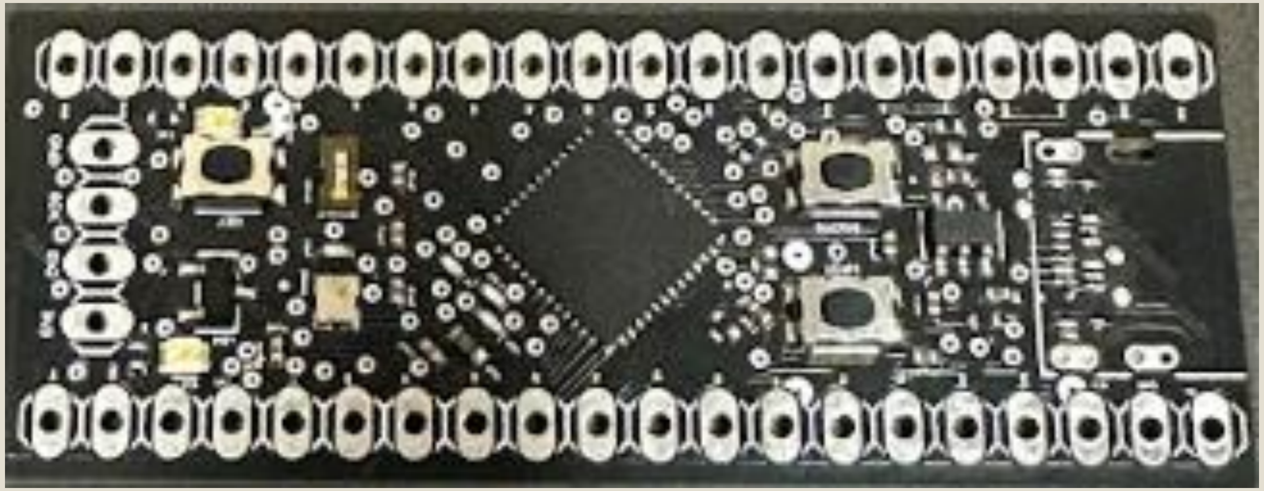
Used to power the laser

Used to power the ESP32

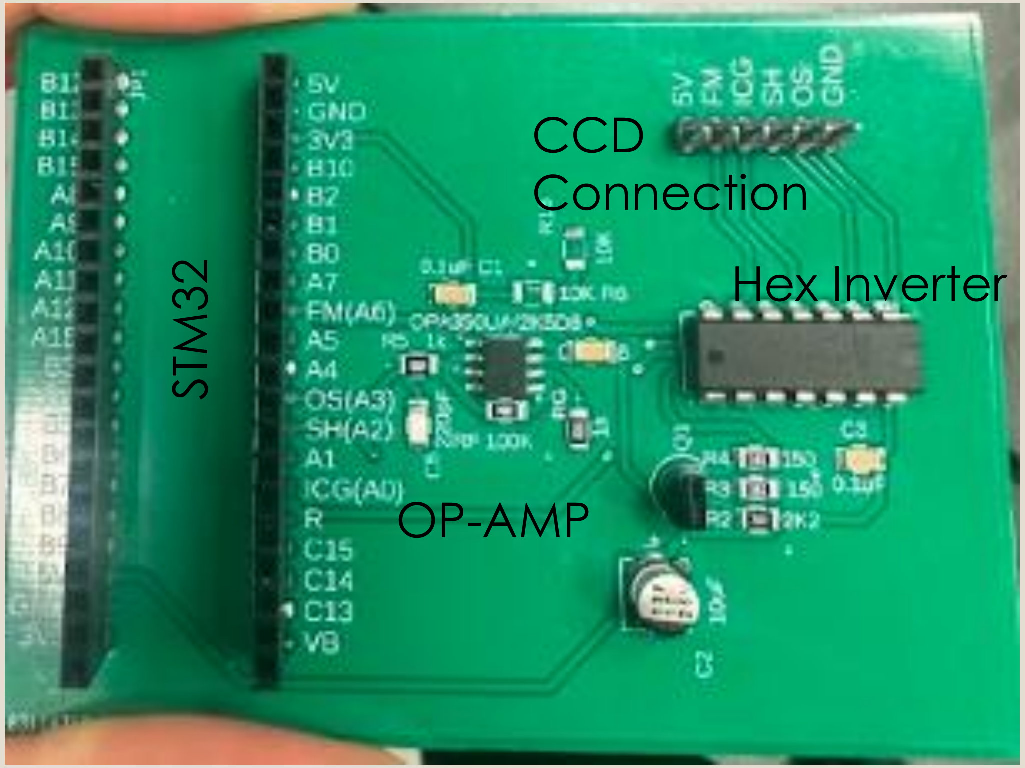
Main Board PCB



STM32 PCB



Signal Amplifying Board



Comparison Algorithms

	Dynamic Time Warping	Euclidean Distance	K-Nearest Neighbors
Speed	Moderate	Fast	Moderate
Accuracy	High	Low	High*
Availability	Moderate	High	Moderate
Implementation Time	Fast	Fast	Moderate

Dynamic Time Warping

- **Used To Calculate Trial-Trial Similarity**

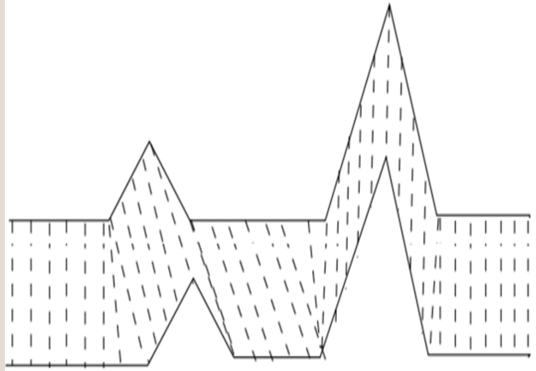
Euclidean Distance

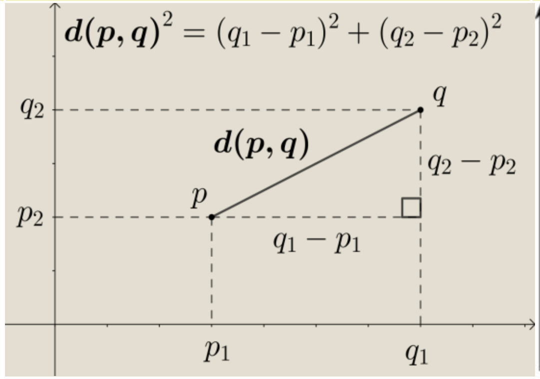
- **Used As DTW Distance Metric**

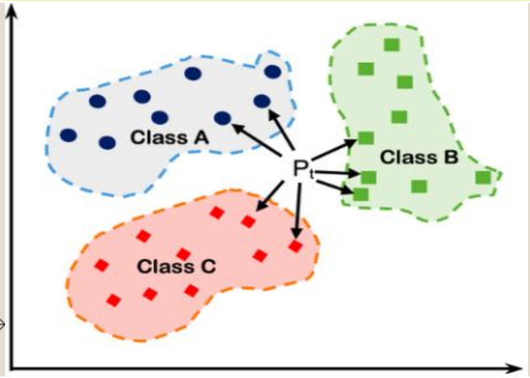
K-Nearest Neighbors

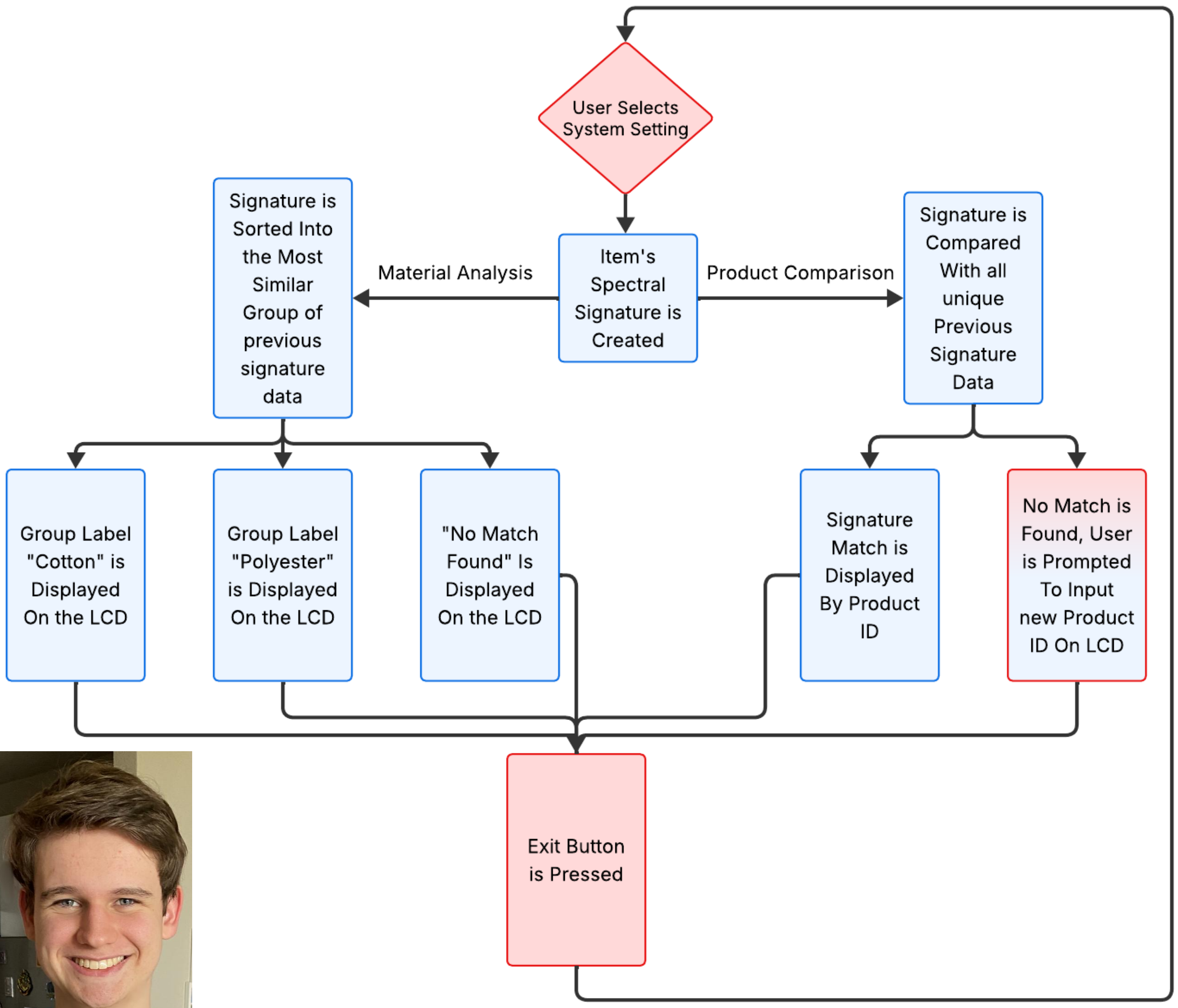
- **Used To Sort DTW Results**

***Varies Strongly by Distance Metric**



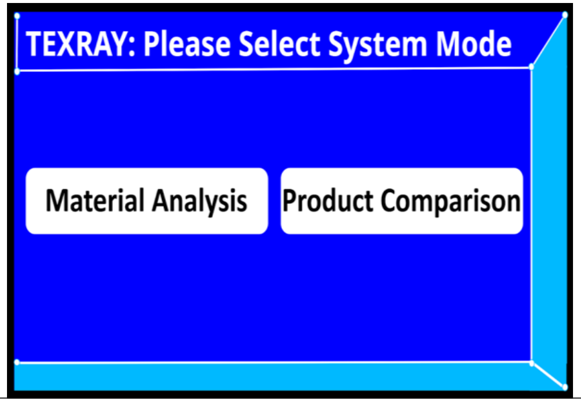




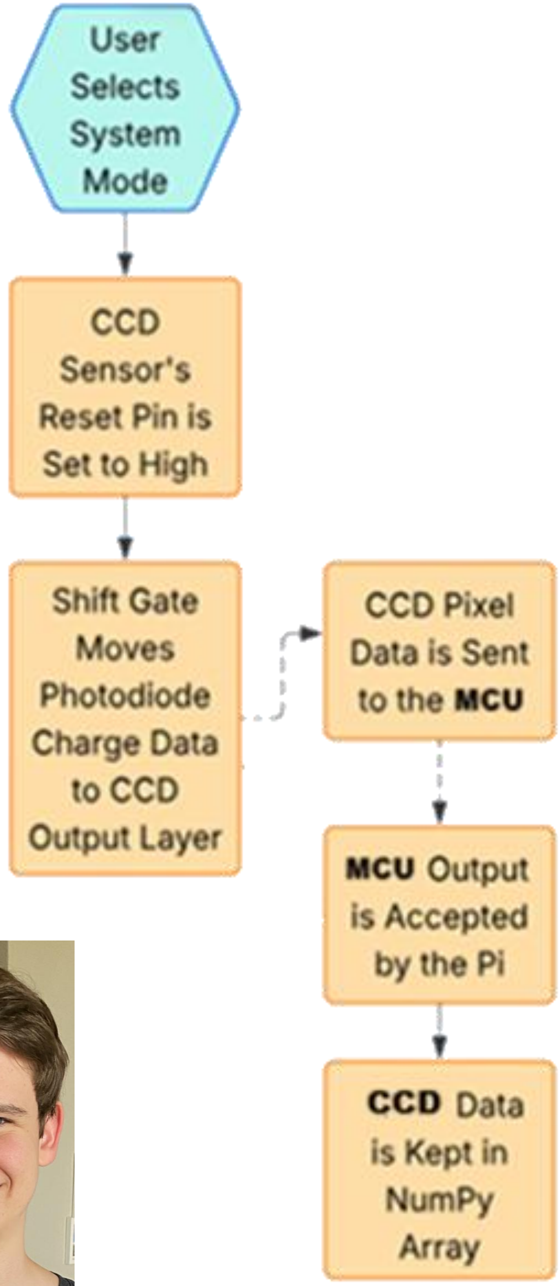


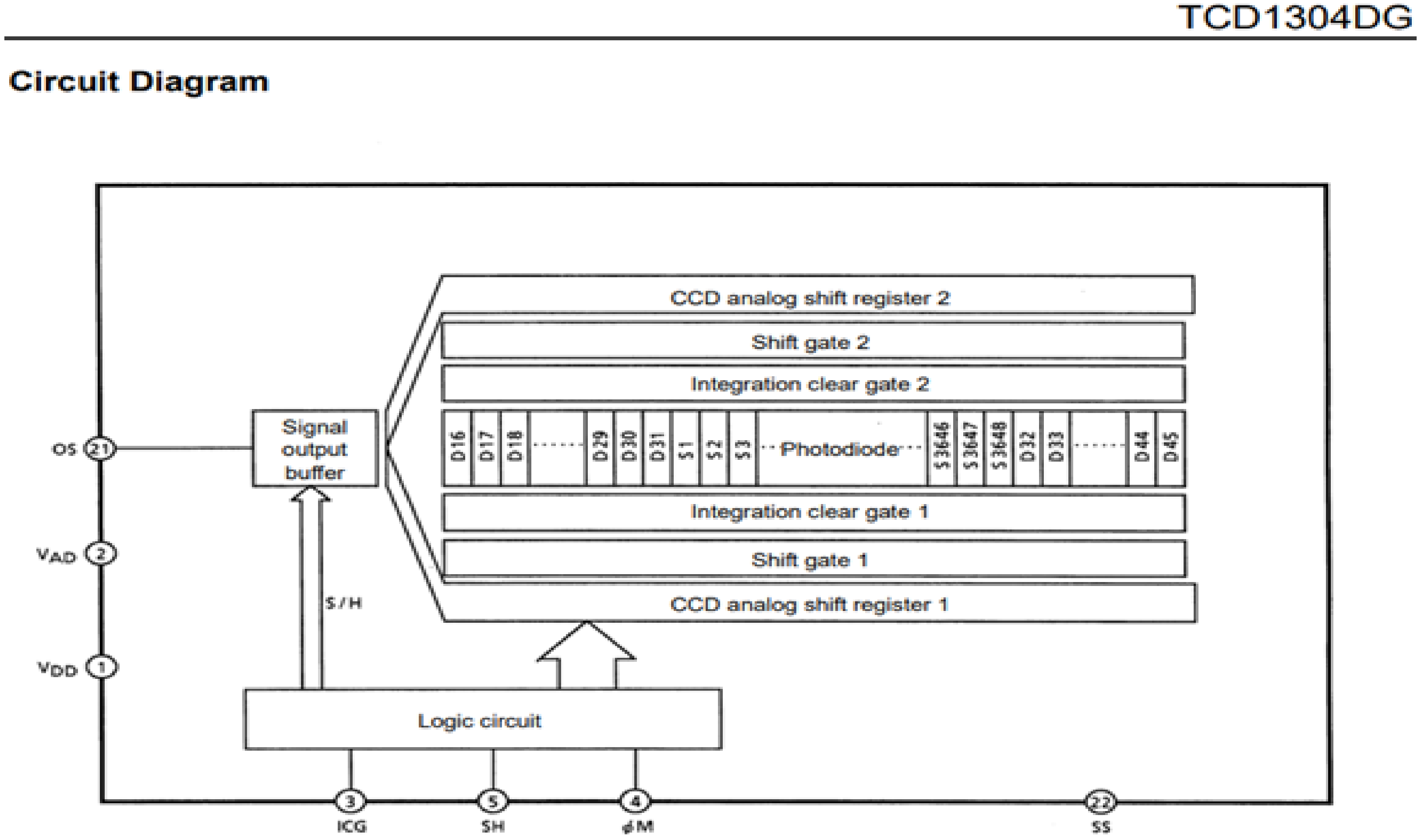
SOFTWARE FLOWCHART

System Mode Selection Screen

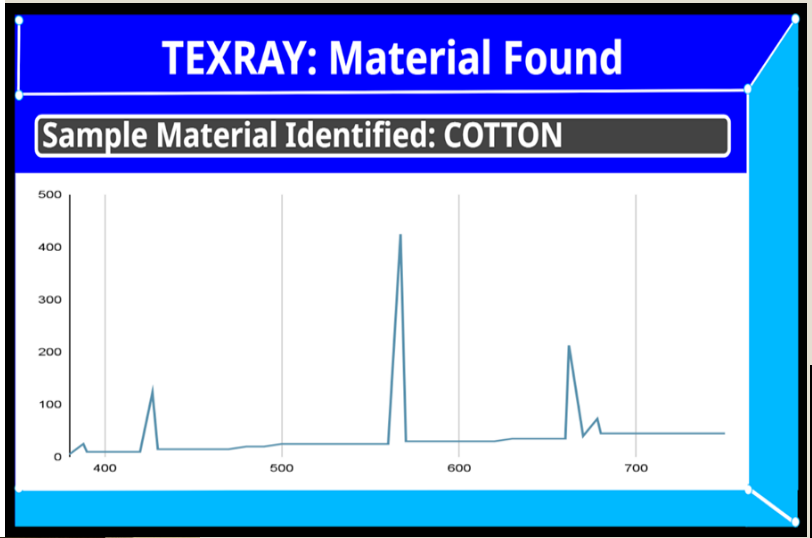


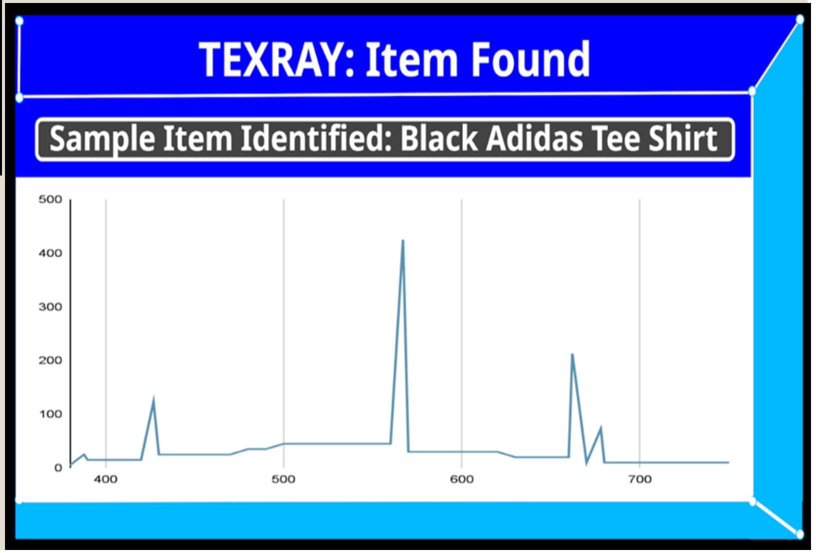
CCD Data Aquisition

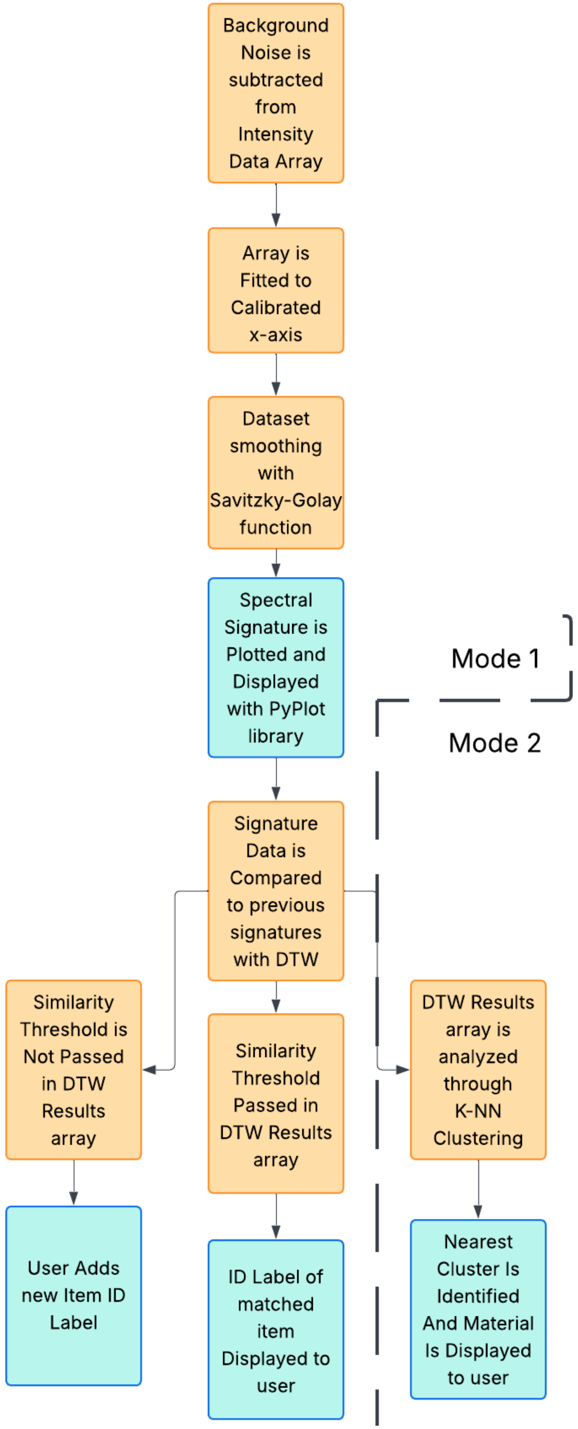




Spectral Signature Generation and Identification







Software Used

Environments

STM32 CubeIDE

ARDUINO

Raspbian

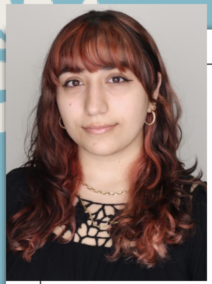
Libraries

NumPy

SciPy

scikit learn

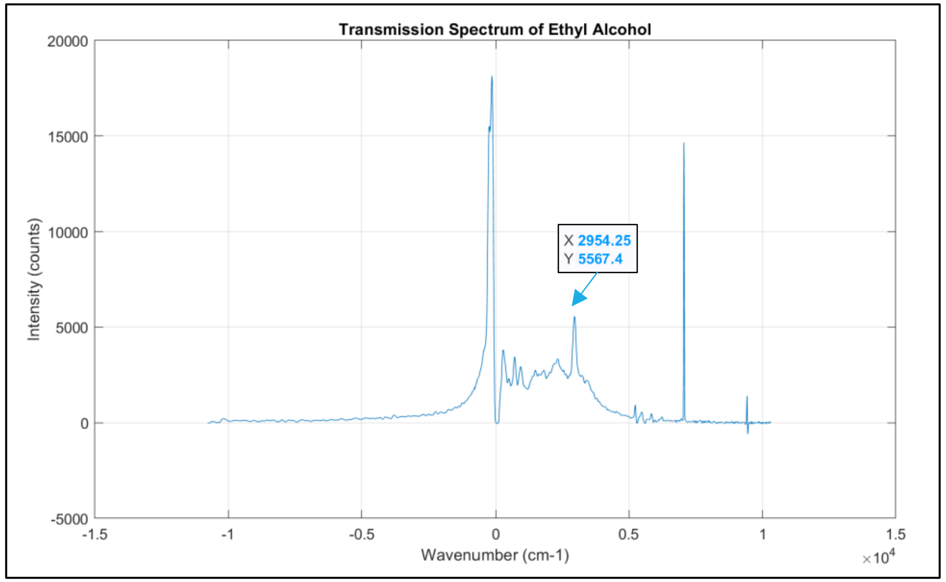
matplotlib

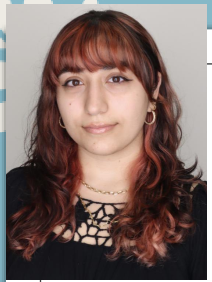


COLLECTION OPTICS PRELIM TESTING

Testing Setup:
- 100 mW DPSS laser with 800 nm pump
- Bandpass filter centered near 532 nm to block pump wavelength
- F = 50 mm focusing lens increasing intensity onto Ethyl Alcohol sample
- F = 50 mm collimating lens to collect Raman scattered light
- 550 nm cut-on longpass filter to isolate Raman signal
- F = 50 mm focusing lens to focus light onto spectrometer fiber
- 10 sec spectrometer integration time

Results:
- Clearly defined peak at 630.5 nm, or 2936 cm^{-1}
- Integration time was sufficient to acquire a signal
- Raman signal discernible from 600 lines/mm groove density
  - Our personal CCD has 1200 lines/mm, meaning higher resolving capabilities
- Linear CCD array in the spectrometer was sensitive enough to detect the signal

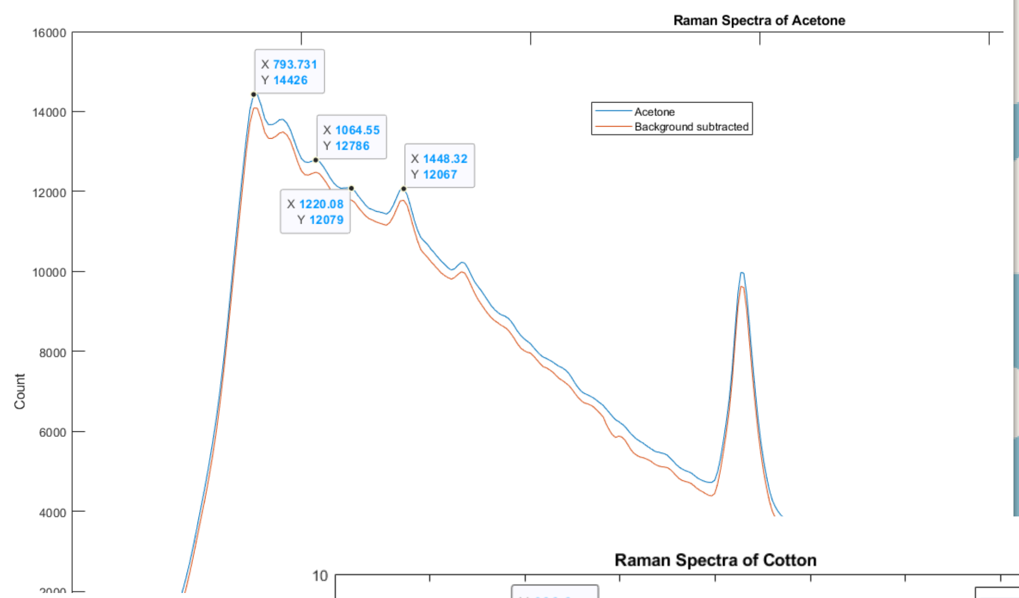




COLLECTION OPTICS FINAL SETUP TESTING

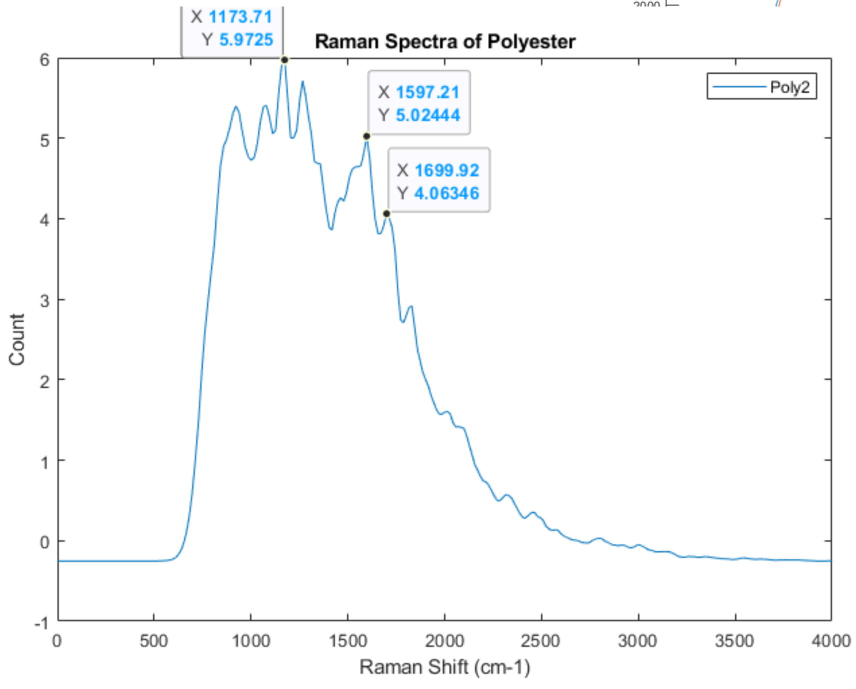
Testing Setup:

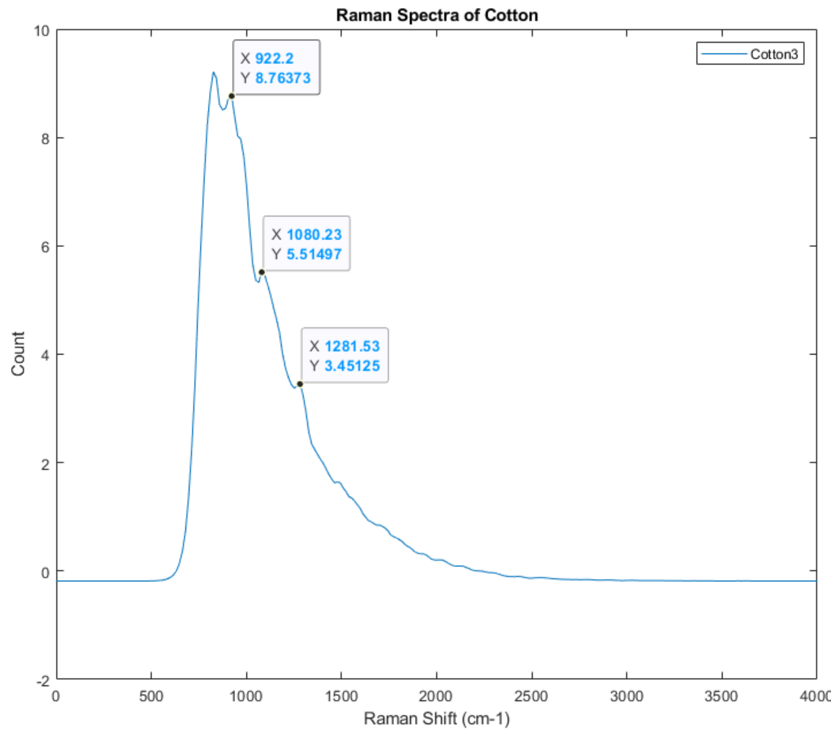
- 30 mW DPSS laser with 800 nm pump
- All components discussed in prior slides
- 10 sec spectrometer integration time
- Tested by coupling signal into commercial spectrometer fiber



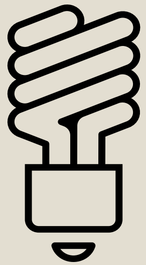
Results:

- Tested with acetone, polyester, and cotton
- Key peaks appeared for acetone and polyester, clearly identifiable each time
- Cotton peaks less distinguishable but still identifiable
- Reproducible results

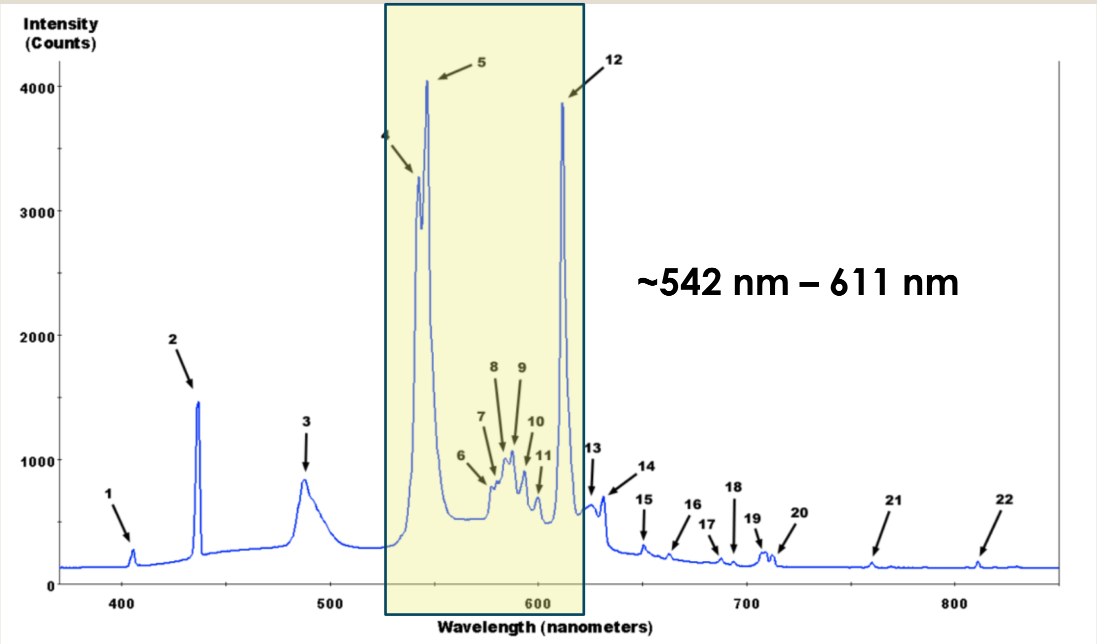




Preliminary Spectrometer Testing

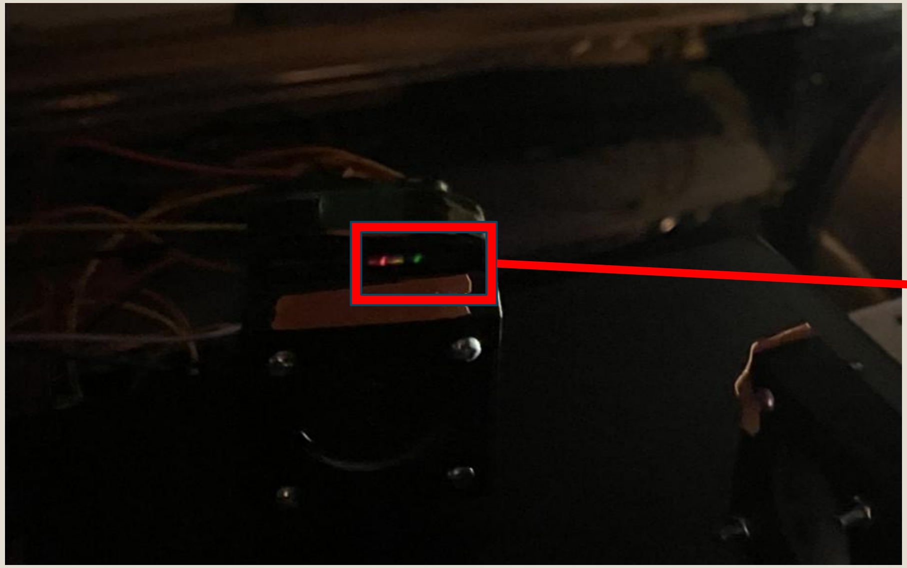


Fluorescent Blub: Mercury and Phosphor emission lines



Peak number	Wavelength of peak (nm)	Species producing peak	Actual line location (nm)
1	405.4	mercury	404.656
2	436.6	mercury	435.833
3	487.7	terbium from Tb^{3+}	~485 to 490
4	542.4	terbium from Tb^{3+}	~543 to 544
5	546.5	mercury	546.074
6	577.7	likely terbium from Tb^{3+} or mercury	576.960 for Hg or ~578 for Tb
7	580.2	mercury or terbium from Tb^{3+}	579.066 for Hg or ~580 for Tb
8	584.0	possibly terbium from Tb^{3+} or europium in $Eu^{+3}:Y_2O_3$	~580
9	587.6	likely europium in $Eu^{+3}:Y_2O_3$	~587
10	593.4	likely europium in $Eu^{+3}:Y_2O_3$	~593
11	599.7	likely europium in $Eu^{+3}:Y_2O_3$	~598
12	611.6	europium in $Eu^{+3}:Y_2O_3$	~611
13	625.7	likely terbium from Tb^{3+}	~625
14	631.1	likely europium in $Eu^{+3}:Y_2O_3$	~630
15	650.8	likely europium in $Eu^{+3}:Y_2O_3$	~650
16	662.6	likely europium in $Eu^{+3}:Y_2O_3$	~661
17	687.7	likely europium in $Eu^{+3}:Y_2O_3$	~687-688
18	693.7	likely europium in $Eu^{+3}:Y_2O_3$	~693
19	707 and 709	likely europium in $Eu^{+3}:Y_2O_3$	~707 and ~709
20	712.3	likely europium in $Eu^{+3}:Y_2O_3$	~712
21	760.0	likely argon	758.9315 or 763.5106 (??)
22	811.0	likely argon	811.531

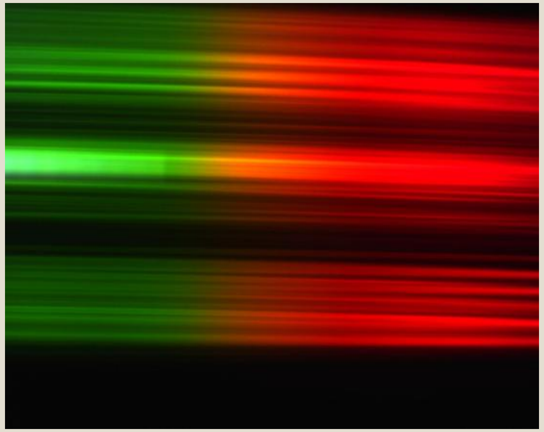
Preliminary Spectrometer Testing Results



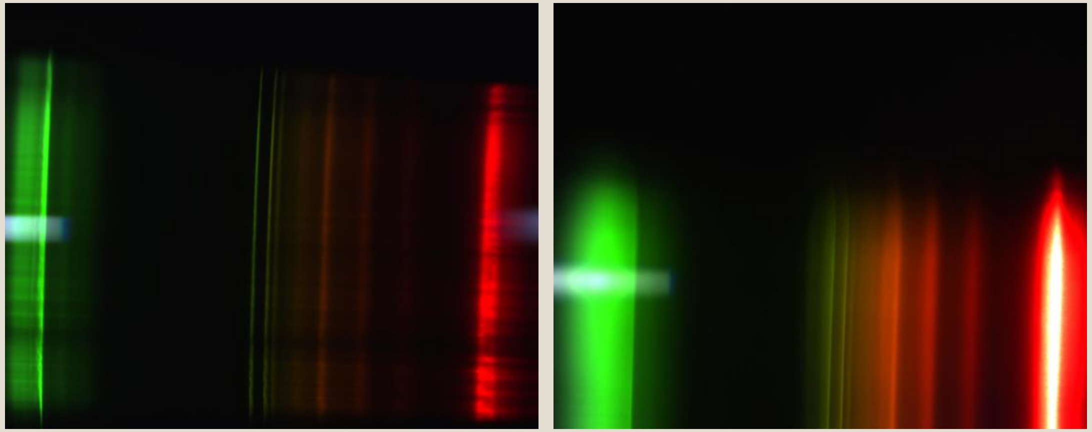
Emission Bands seen along the CCD

Two images of the emission bands taken with a CMOS sensor

Thorlabs
CMOS
Camera

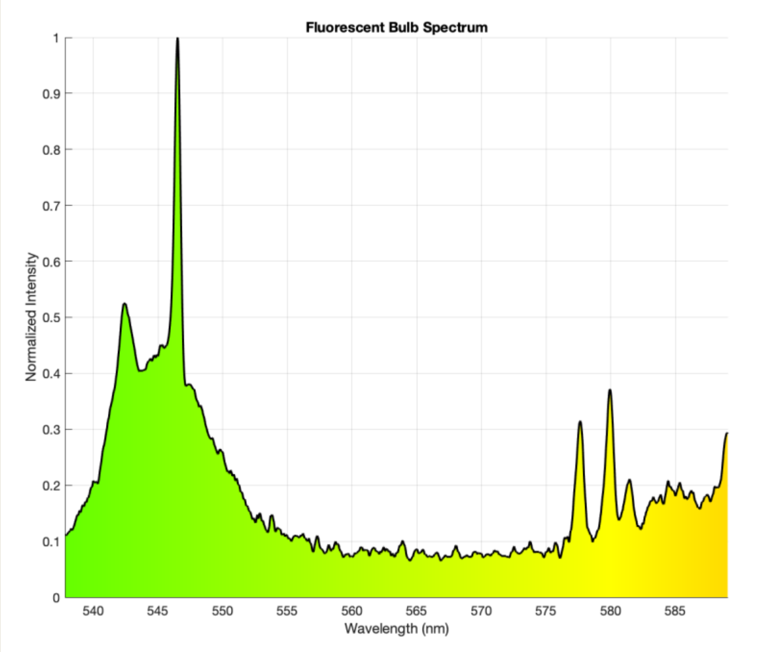


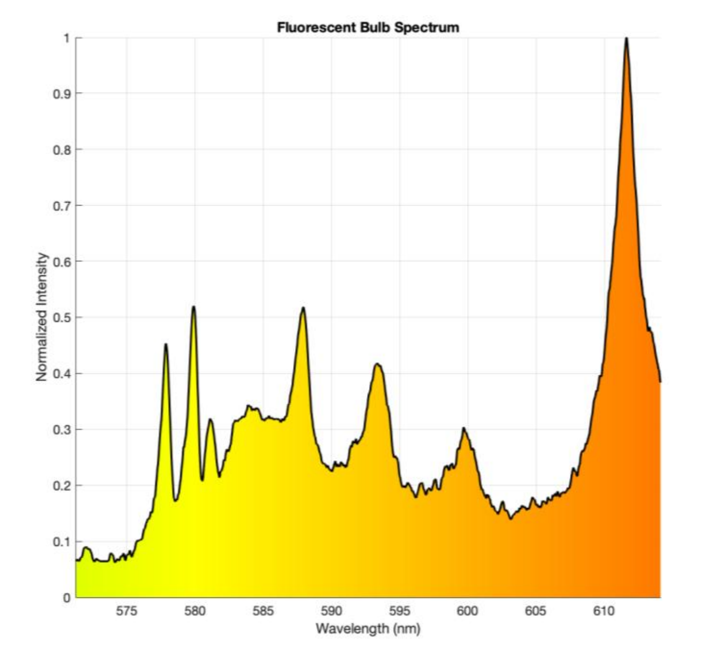
Halogen Source

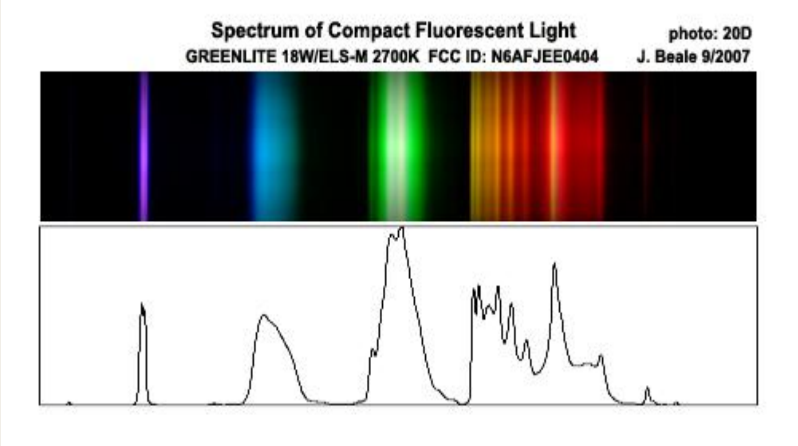


Fluorescent Source: in focus + defocused

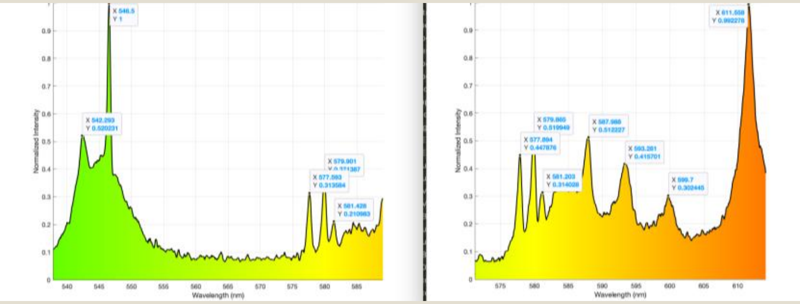
Preliminary Spectrometer Testing Results



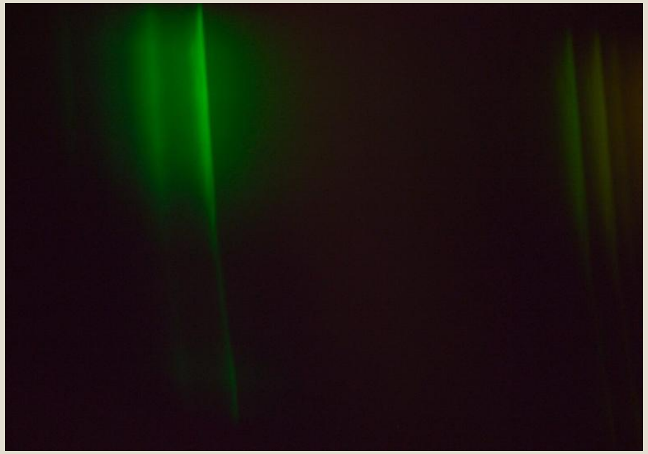


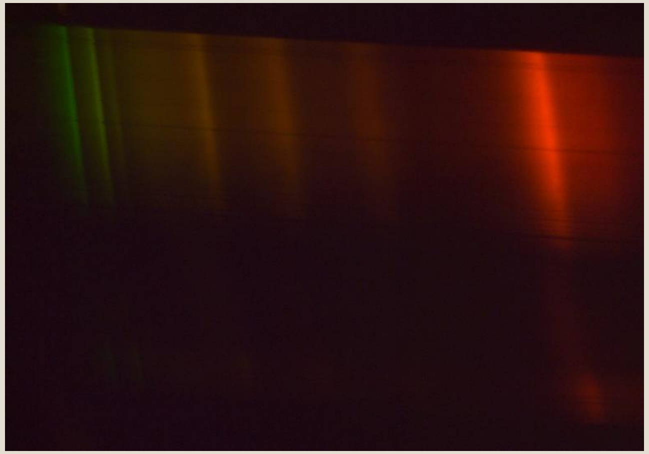


Reference Spectrum



Avg FWHM: 0.4579 nm

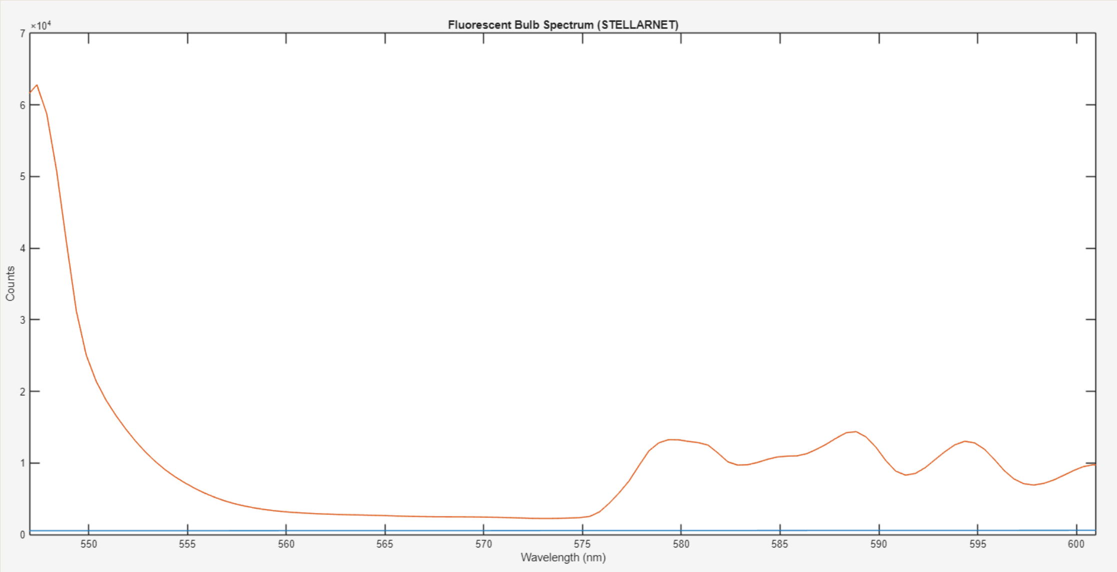




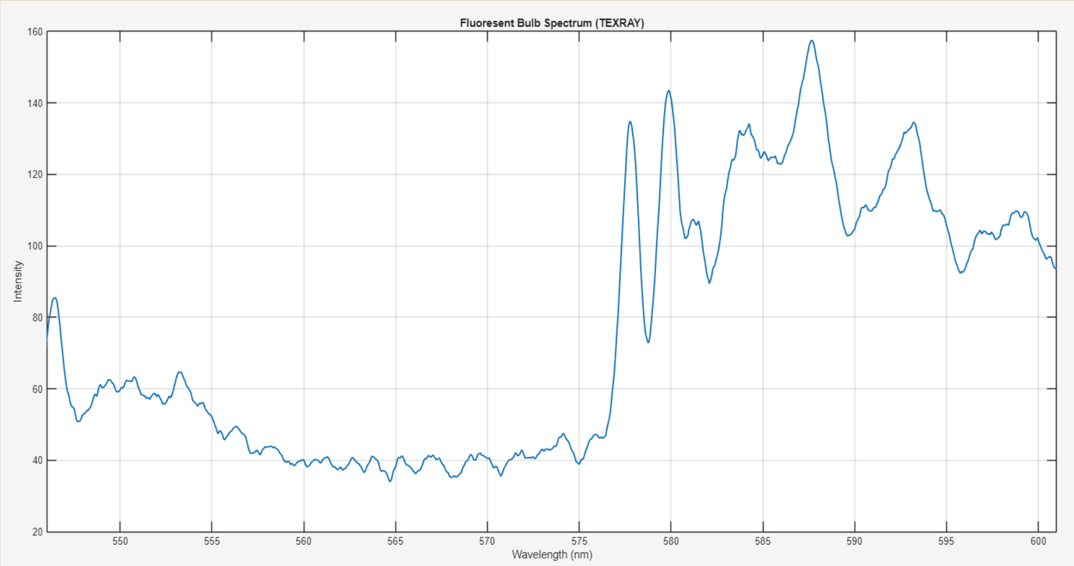
Experimental Results

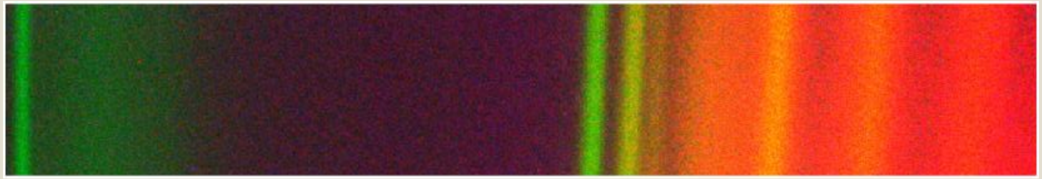
Preliminary Spectrometer Testing Results

Commercial Spectrometer



TEX-RAY Spectrometer





Sorting Algorithm Results

Results achieved when testing our sorting algorithm with data collected from a commercial Raman spectrometer:

Total Product Matching Accuracy: 97.2% (175/180 Trials)

Shirt Trial 1: 3: Correct ✓ (2/3) | 5: Correct ✓ (3/5) | 7: Correct ✓ (5/7) | 9: Correct ✓ (7/9)
Shirt Trial 2: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 3: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 4: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 5: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (6/7) | 9: Correct ✓ (9/9)
Shirt Trial 6: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 7: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | Correct ✓ : (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 8: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 9: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Shirt Trial 10 : 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)

Jacket Trial 1: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 2: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 3: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 4: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 5: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 6: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 7: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 8: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Jacket Trial 9: 3: Correct ✓ (2/3) | 5: Correct ✓ (3/5) | 7: Correct ✓ (4/7) | 9: Correct ✓ (6/9)
Jacket Trial 10: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)

Material Sorting Accuracy: 96.1% (173/180 Trials)

Polyester Trial 1: 3: Correct ✓ (2/3) | 5: Correct ✓ (3/5) | 7: Correct ✓ (5/7) | 9: Correct ✓ (7/9)
Polyester Trial 2: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 3: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 4: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 5: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (6/7) | 9: Correct ✓ (8/9)
Polyester Trial 6: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 7: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | Correct ✓ : Y (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 8: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 9: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Polyester Trial 10 : 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)

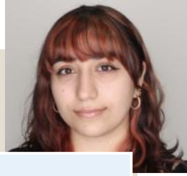
Cotton Trial 1: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 2: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 3: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 4: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 5: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 6: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 7: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)
Cotton Trial 8: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (8/9)
Cotton Trial 9: 3: Correct ✓ (2/3) | 5: Correct ✓ (3/5) | 7: Correct ✓ (4/7) | 9: Correct ✓ (6/9)
Cotton Trial 10: 3: Correct ✓ (3/3) | 5: Correct ✓ (5/5) | 7: Correct ✓ (7/7) | 9: Correct ✓ (9/9)

* 3, 5, 7, 9 Represent k in k-Nearest Neighbors

Successes and Difficulties

	Laser Source	Spectrometer	Mounting Optics	CCD Data Acquisition	PCB
Difficulties	Balancing linewidth and laser output power at 532 nm	Finding a combination of collimation and focusing lenses for best resolution	Creating custom fitted 3D-printed mounts for delicate and expensive optics	The precision necessary to achieve the timing requirements of the CCD output signal delayed the success of this area of the project	Creating a design for the main board ensuring minimal noise
Successes	Finding an affordable laser with narrow spectral linewidth	Simulated an acceptable combination of optics that upholds our requirements	Maintaining the integrity of alignment with 3D-printed mounts	The code driving the CCD sensor and comparing spectral signature data across several trials has been completed	Approved power supply design for the system

Bill of Materials



Item	Part number	Cost per unit	Quantity	Total Cost
Laser diode module	Q-BAIHE 532 nm laser module	$43.98	1	$43.98
Dichroic mirror (Beamsplitter)	Chroma T550lpxr	$250	1	$250
Long Pass Filter	Chroma ET542lp	$365	1	$365
Plano-convex Focusing Lens	Edmund Optics #48-423	$31	1	$31
VIS 0° Coated Achromatic Lens	Edmund Optics #47-639	$120.84	1	$120.84
Bandpass filter	Edmund Optics #26-981	$74.20	1	$74.20
Plano-concave lens	Thorlabs LC2969	$30.74	1	$30.74
Plano-convex lens	Thorlabs LA1509	$25.04	1	$25.04
Mirror	Edmund Optics #36-043	$35.51	2	$71.02
Slit	Thorlabs S50K	$119.13	1	$119.13
VIS 0° Coated Achromatic Lens	Edmund Optics #47-637	$120.84	2	$241.68
Diffraction grating	Thorlabs GR25-1205 Grating	$128	1	$128
CCD	Toshiba TCD1304DG	$34	1	$34
PCBs		$25.46	1	$25.46
LCD	B0CXTFN8K9	$32.99	1	$32.99
Raspberry Pi	B0CK3L9WD3	$69.49	1	$69.49
ESP32 Development Board	B0718T232Z	$9.99	1	$9.99
3.3 Volt Regulator	LM2576SX-3.3/NOPB	$3.72	1	$3.72
5 Volt Regulator	LM22679TJ-ADJ/NOPB	$6.10	1	$6.10
12 Volt Regulator	LM22679TJ-5.0/NOPB	$13.10	1	$13.10
Battery power supply	PS12-BK60-LF60NA	$53.47	1	$53.47
CP2102	CP2102N-A02-GQFN28	$4.32	1	$4.32
STM32 Chip	STM32F401CCU6	$5.20	1	$5.20
ESP32 Chip	ESP-WROOM-32D	$5.20	1	$5.20
IC Components (Resistors, Capacitors, Inductors, LEDs, etc.)		$56.14	NA	$56.14
Fabric Samples		$0	1	$0
Total Cost				$1819.81

Work Distribution

Danielle	Ariana
• Spectrometer Design • Spectrometer Housing	• Collection Optics Design • Optical Mounts Design
Austin	**Cameron**
• CCD Data Acquisition • Signal Data Processing • Spectral Signature Data Analysis & Classification	• PCB Design • Power Distribution

Testfabrics, Inc.

Your Source for Quality Materials

CHROMA®

Thank You