Automated Parameter Adjusting Laser Engraving System (APALES)

Group 5

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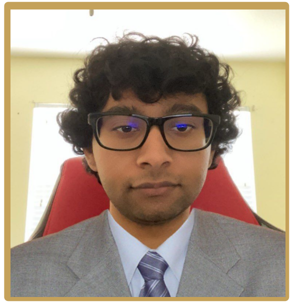

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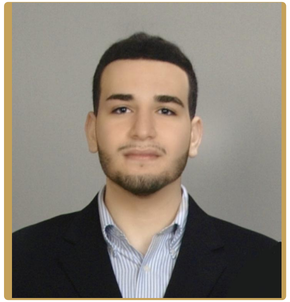

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Background

- ➢ Laser engraving requires adjusting laser parameters (power & scan speed) depending on the material of choice
- ➢ Laser engraving systems from all budget ranges require the user to change laser parameters manually
- ➢ It can be tedious to remember the optimal laser parameters for each material and manually input the specifications for each new engraving

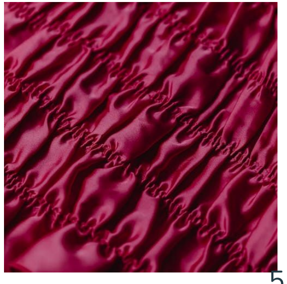
Motivation

- Incorporating a system to automatically detect the material being engraved saves the user time and eliminates the reliance of memory to begin engraving a material
- Reusing the same materials becomes much simpler and more streamlined with an automated recognition system
- Simplifies user experience and makes laser engraving more frictionless

Goals

- **Core goals:**
- *C1.0*: APALES will be safe to operate without outside safety equipment
- *C2.0:* APALES will be able to engrave basic patterns on materials
- *C3.0:* APALES is economical
- *C4.0:* APALES will be able to differentiate wood, leather, and fabric with 80% accuracy

- **Advanced goals:**
- *A1.0*: APALES will be able to engrave patterns with 0.5 mm resolution
- *A2.0:* APALES will be equipped with engraving and cutting capabilities for wood,
- leather, and fabric up to 2 mm thickness
- *A3.0:* APALES will be able to identify the laser-to-material distance
- *A4.0:* APALES will be able to differentiate 5+ materials with 85% accuracy



- **Stretch goals:**
- *S1.0*: APALES will be able to engrave patterns with 0.1 mm resolution
- *S2.0:* APALES will automatically adjust the laser height to adjust for material
- thickness
- *S3.0:* APALES will be able to differentiate 10+ materials with 90% accuracy

Objectives

- Safety measures such as: a protective cover to block harmful laser radiation, fans for ventilation, an emergency stop, and following class IV laser regulations by using laser safety goggles.
- Engrave on materials like wood, leather, and fabric. Create basic patterns like dots, squares, and circles. These early starting tests will lay the groundwork for a extensive engraving system.
- Implementing high quality optics for the spectrometer and laser module will increase the resolution of the spectrum reflected off the material surface and the resolution of the engraved patterns. Our spectrometer will be made with a high quality diffraction grating, optical fiber, and lenses.

Requirements and Specifications

Component	Parameter	Specification
Laser	Power	4 W
Laser	Wavelength	450 nm
Focusing Lenses	Effective Focal Length	30 mm
Diffraction Grating	Lines per mm	600 ln/mm
A4988 Drivers	Current Limit	1 Amp
Power Supply Conversion	Voltage	12 V - 5 V

Laser System Comparisons

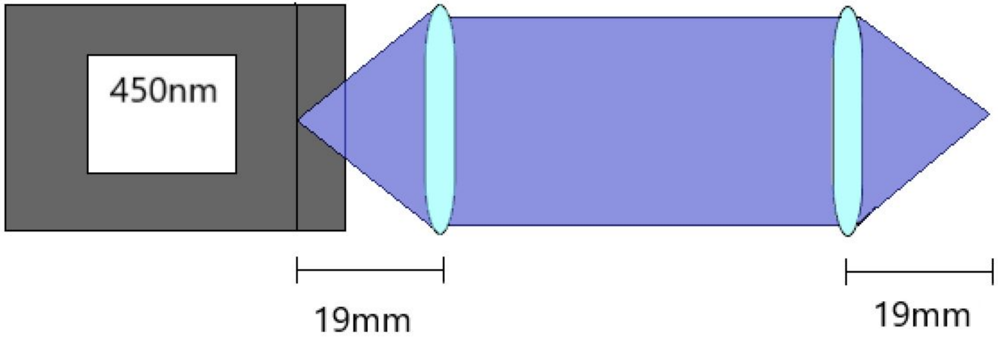
Laser Diode	Fiber Laser
Lightweight	Lightweight
Low cost	Expensive
High power	High power
Easily implementable	Easily implementable
Rectangular beam profile	Circular beam profile

Single Lens Focus	Double Lens Focus
Fixed working distance	Adjustable working distance
Lower cost	Higher cost
Low complexity	Potentially higher complexity
Lower beam quality	Better beam quality

Laser System Hardware and Confirmed

Schematic of Laser Diode and Focusing System

- 450nm, 5W laser diode
- Collimating lens, focal length 19mm, lens placed one focal distance from the laser emitter (not front of module)
- Focusing lens, focal length 19mm
- Distance between the two lenses is variable



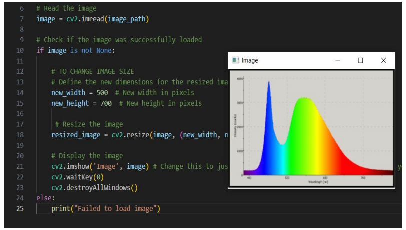
Software Comparisons and Confirmed

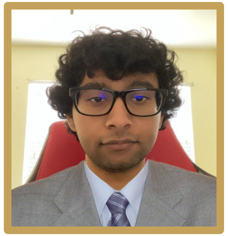
Arduino IDE	Visual Studio Code IDE	Code Composer Studios
C, C++, Assembly	C, C++, Python, Java, Javascript, Haskell, etc.	C, C++
Cannot Multitask	Cannot Multitask	Can Multitask
User friendly	User friendly	User friendly
Arduino boards	Embedded processors and programming and software	Embedded processors (MSP430)

Software Comparisons and Confirmed

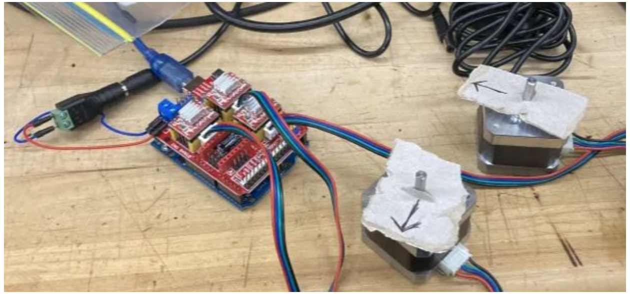
MongoDB	MySQL	LaserGRBL	Database without DBMS
User friendly UI	CMD, tables and UI	User friendly UI	Create UI manually, all code
Create database table manually	Create database table manually	Built in database that can be edited	Create database table manually
Open source	Open source	Open source	Not Open Source
Used for flexibility and uses JSON documents to store data. Fast at processing. Real-time analytics and mobile apps	Used managing and manipulating data. Using a structured query language and in web applications.	Used for CNC machines and configurations	Used to have tables. No structure and standard way of managing data efficiently.

Software Details





- ➢ OpenCV (computer vision library) used to communicate and send image data through the system during the spectroscopy system for image processing.
- ➢ Visual Studio Code: Used to program and send and receive data. The Python language will mostly be used for the libraries that it offers to be used for the spectroscopy system and more (MATLAB, OpenCV).
- ➢ LaserGRBL will be used as a software that works with CNC machines and for automation. Has a built in database we can configure and it is open source to work with our project.
- ➢ Arduino IDE: Good for testing parts (motors, sensors, switches, controllers) and useful for working with the NEMA 17 motors.

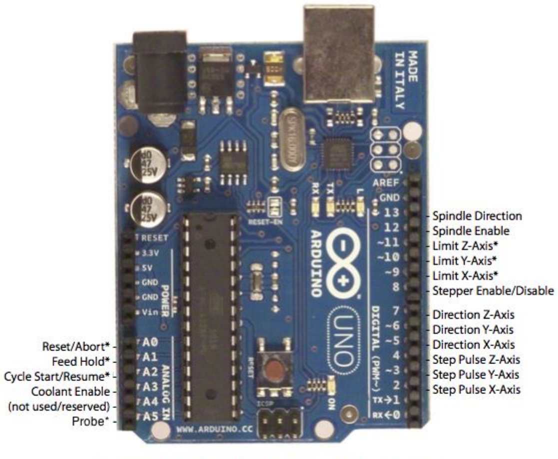


Laser Control Software Use

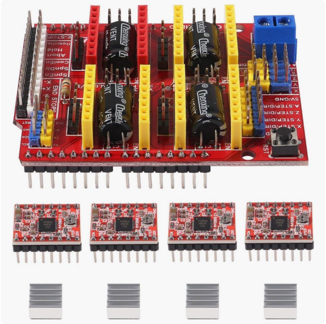
LaserGRBL	Universal G-code Sender (UGS)	Python pyserial package	GRBL (Arduino Firmware)
Accessible GUI, features flash tool for GRBL firmware, supports hotkeys for testing laser power and stepper motor movements	GUI similar to LaserGRBL, more general purpose CNC applications, supports other controller firmwares	Able to generate/modify G-code manually and send to target device (Arduino MCU)	Receives and parses G-codes from host machine (PC), converts g-codes into step + direction signals for stepper motors
Contains material DB with job parameters for various commercial laser engravers	Contains hotkeys and job preview, useful for calibrating our gantry system, tweaking steps/mm	Can integrate material detection component (spectroscopy + OpenCV) and parameterization of g-code	Compatible with Atmega328P MCU, same as Arduino UNO board, supports use of spindle (mill) or laser CNC machine

GRBL Testing

- Pinout for GRBL supports use of Laser PWM (replaces spindle speed). v0.9 slightly different from v1.1
- GRBL 1.1 supports variable PWM for laser while the device is moving, this prevents corners from being over burnt.
- In testing we found that the 1.1 version was necessary for certain g-codes controlling laser PWM, will flash newer version onto our custom controller
- Testing was done using Arduino UNO Dev board with CNC Shield fitted on top.
- A4988 Driver boards are used to “drive” the Nema17 stepper motors using an H-bridge. Driver boards pair well with Nema17’s current requirement



* - Indicates input pins. Held high with internal pull-up resistors.



Pyserial Package

- Alternative to using existing GUI applications for sending g-codes on host device (PC)
- Allows us to parse G-code file and strip comments before sending to Arduino with GRBL.
- Impose delay in g-code sending sequence based on response from GRBL, serial read and transmit.
- Closed loop system can be implemented on a per g-code line basis

gcode.py | simple_stream.py M ×

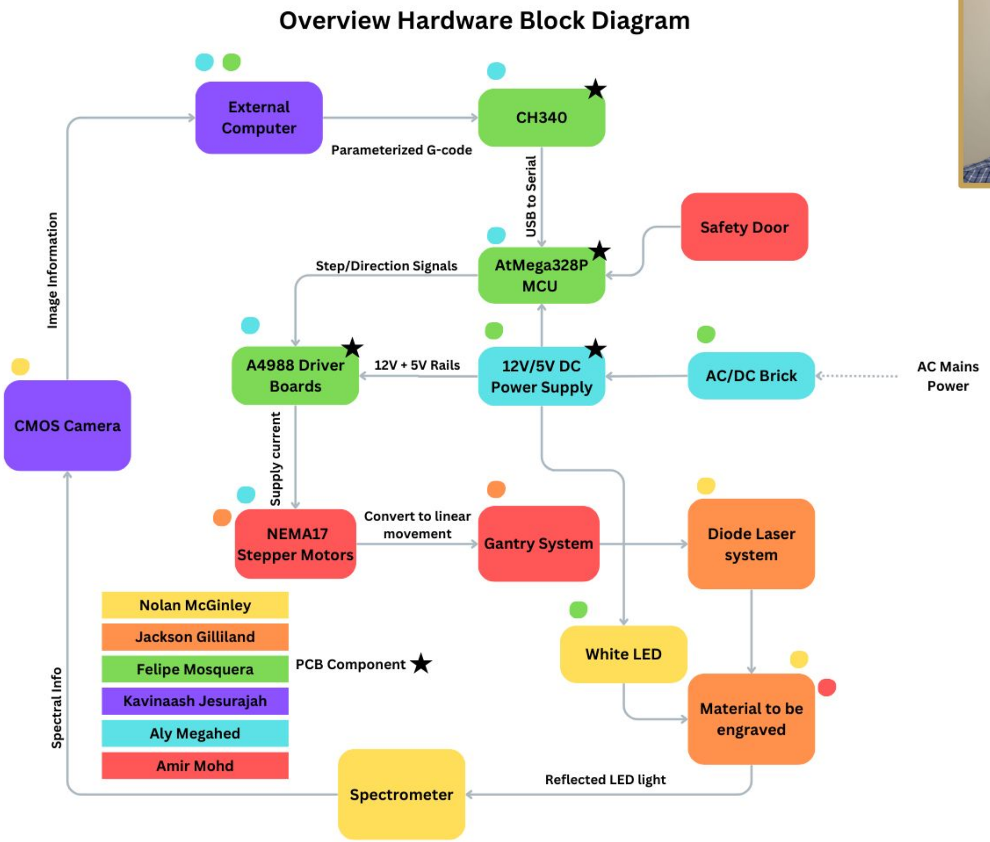
github_example > python_to_GRBL > simple_stream.py > ...

```python
            if grbl_response != 'ok':

                if grbl_response.find('Idle') > 0:
                    idle_counter += 1

            if idle_counter > 10:
                break
    return


def stream_gcode(GRBL_port_path,gcode_path):
    # with contect opens file/connection and closes it if function(with) scope is left
    with open(gcode_path, "r") as file, serial.Serial(GRBL_port_path, BAUD_RATE) as ser:
        send_wake_up(ser)
        for line in file:
            # cleaning up gcode from file
            cleaned_line = remove_eol_chars(remove_comment(line))
            if cleaned_line:  # checks if string is empty
                print("Sending gcode:" + str(cleaned_line))
                # converts string to byte encoded string and append newline
                command = str.encode(line + '\n')
                ser.write(command)  # Send g-code

                wait_for_movement_completion(ser,cleaned_line)

                grbl_out = ser.readline()  # Wait for response with carriage return
                print(" : " , grbl_out.strip().decode('utf-8'))



        print('End of gcode')
```

Integrating with Spectroscopy

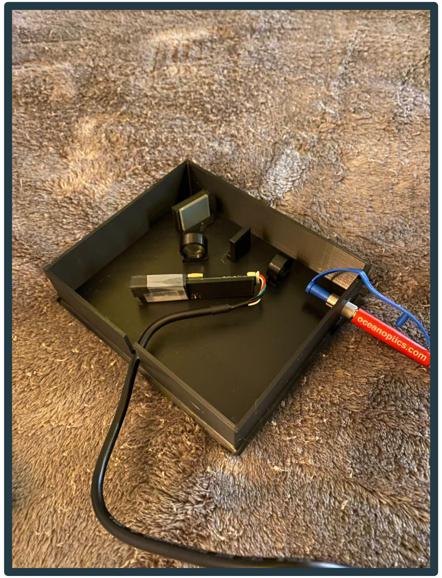
- OpenCV library allows us to integrate spectroscopy data, classification algorithm and g-code parameters into single Python program.
- PC acts as a hub, receives and processes image data, and makes changes to feed rate and laser power according to material.
- OpenCV facilitates real-time access to CMOS camera in spectroscopy system. Connected to PC via USB

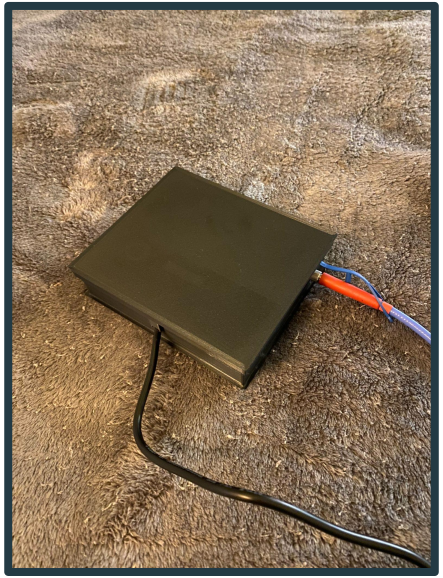
Hardware Block Diagram:



Spectroscopy System

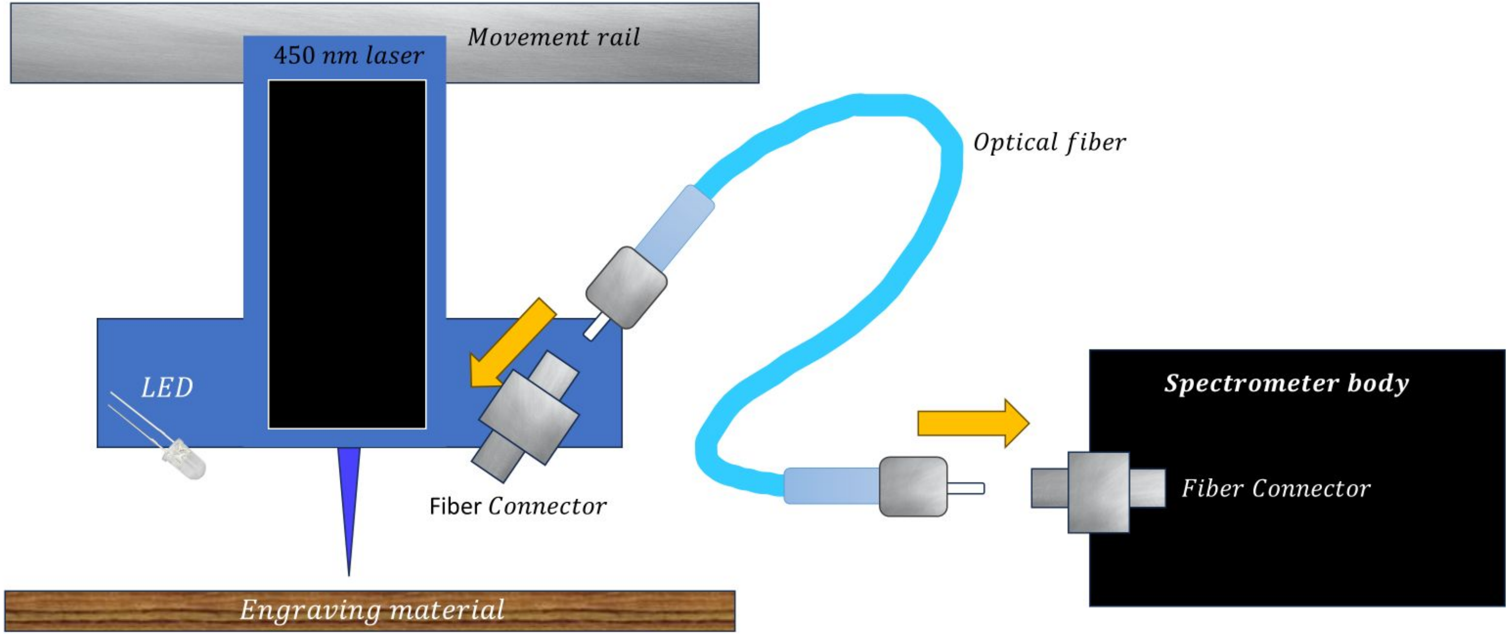
- Collects reflected light from material and generates a spectrum in order to identify the material that will be used for engraving
- Utilizes a fiber optic cable for light collection and a diffraction grating for spectrum analysis
- Body is compact and can be tucked away underneath the body of the engraving system



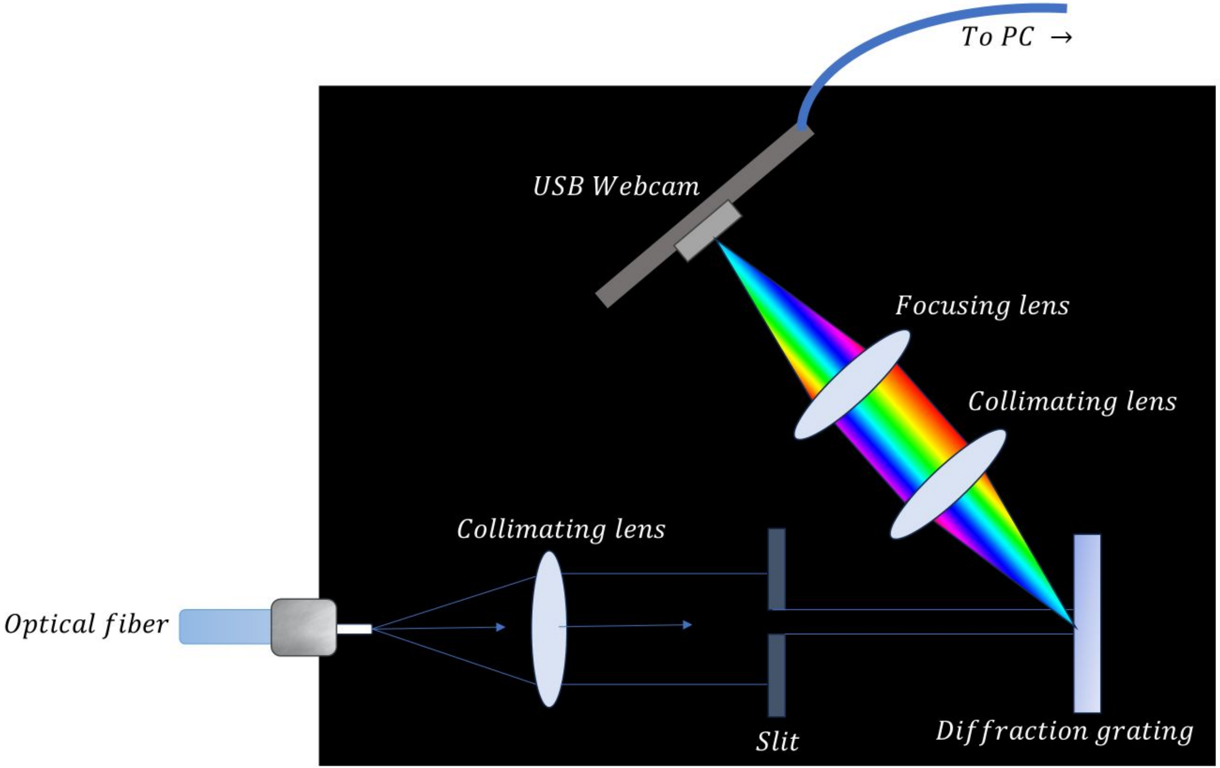


Body of prototype of spectrometer (2/6/24)

Spectroscopy System Design

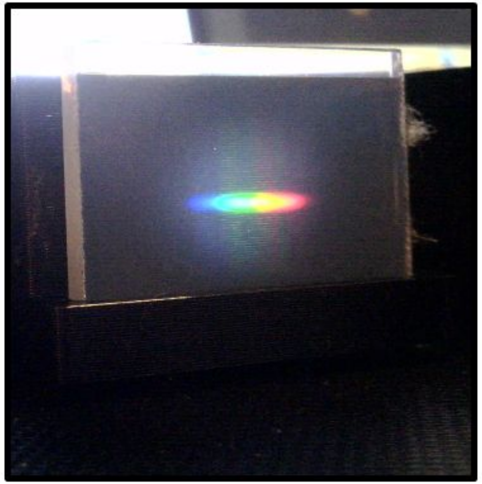


Spectroscopy System Design

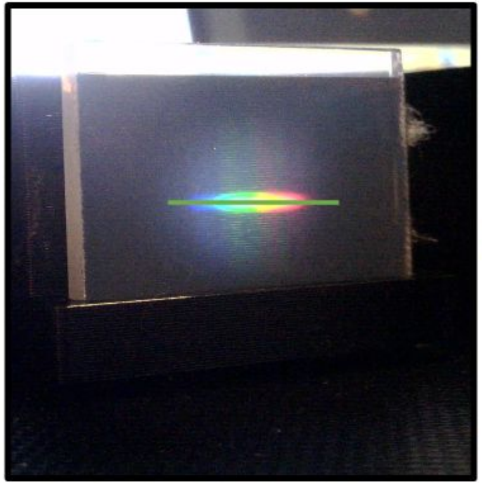


Spectroscopy System Design

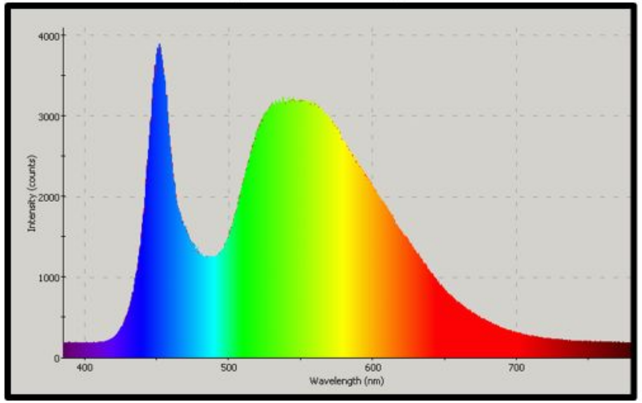
Image from USB webcam



1D slice taken



Spectrum generated and compared to stored spectra to find match



PCB Design - Overall Schematic

PCB → Components → Connections

PCB

Role: To provide a seamless board to power, receive, and transmit data throughout the entire system

Components: Lightweight yet durable material made with an FR-4 epoxy finish

Features: Holes for mounting, as well as copper finish within middle.

Design Considerations: Include pins for necessary components (Motors, Drivers, etc)

Components

Role: Included to safely transmit current and voltage

Material: Simple components made using wire, carbon film, foil, etc.

Features: Using either SMD of 0805 or through hole EU

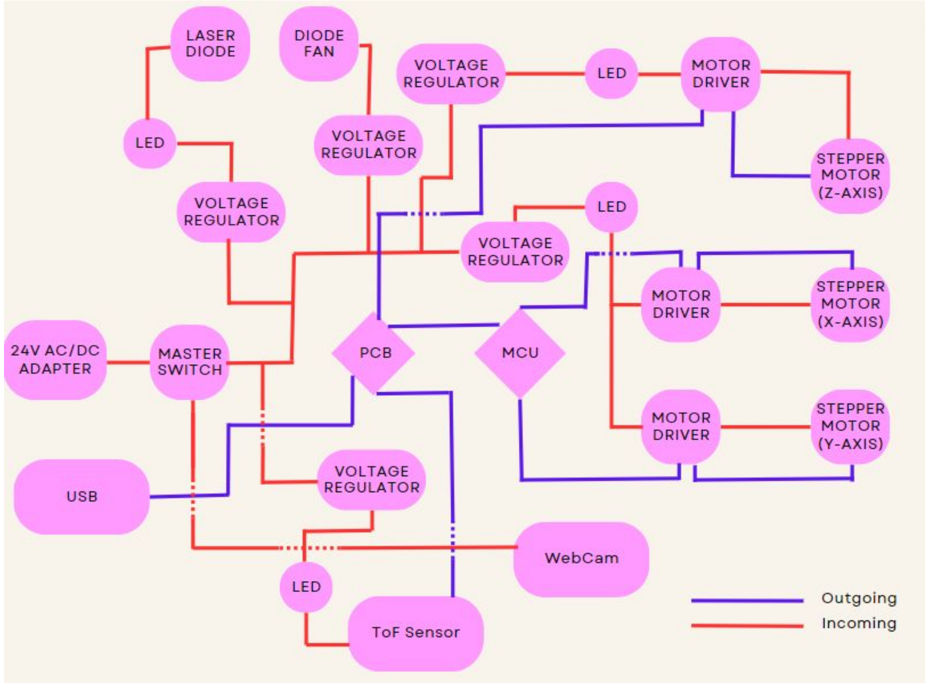
Design Considerations: Include uniform power distribution.

Connections

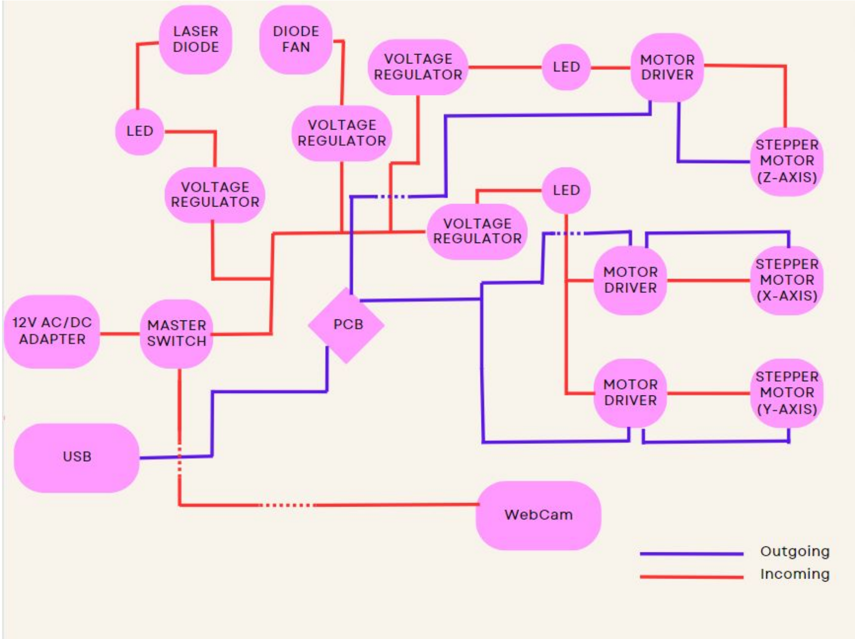
Features: Typical requirements such as clocks, regulators, etc. These connections are done in support of specific circuitry needed for our project

Design Considerations: Ensure pin optimization for all our necessities

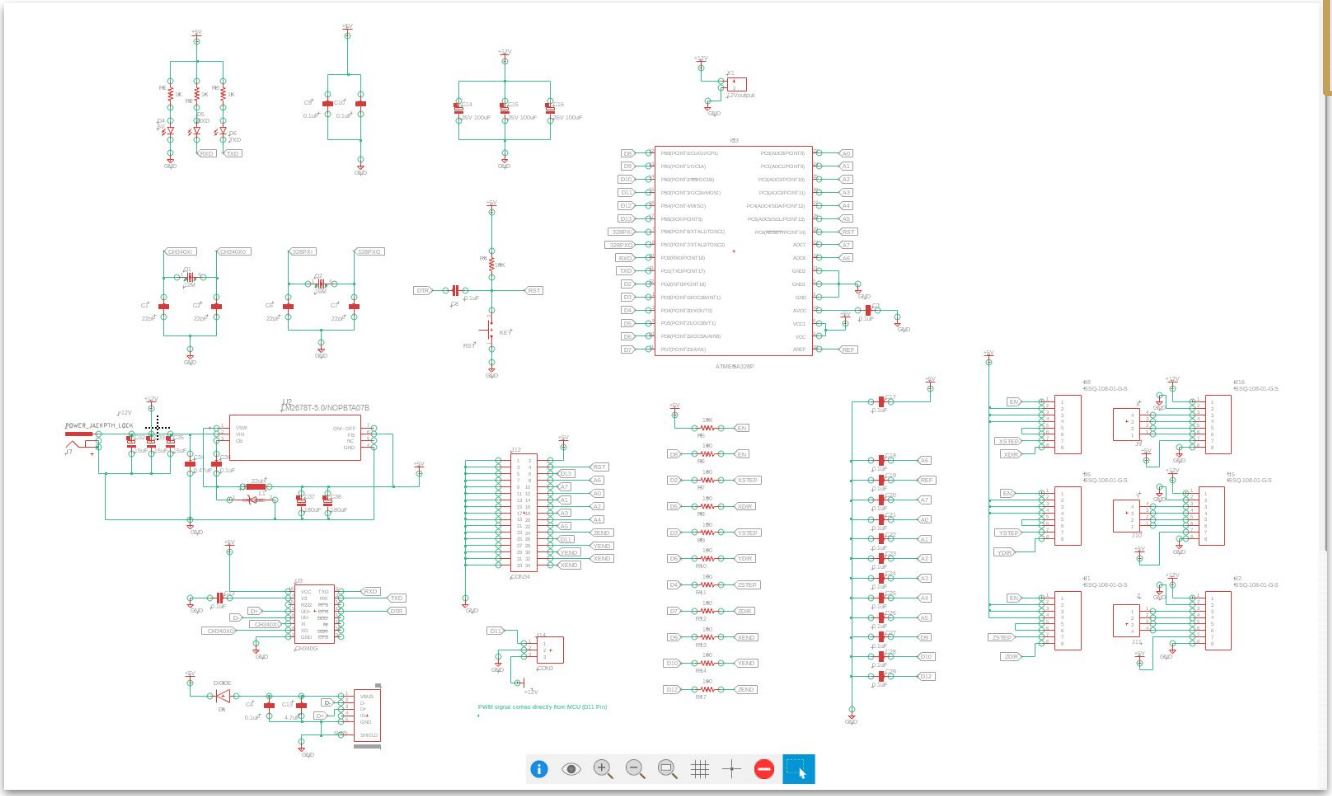
Hardware Design - Overall Schematic (OG)



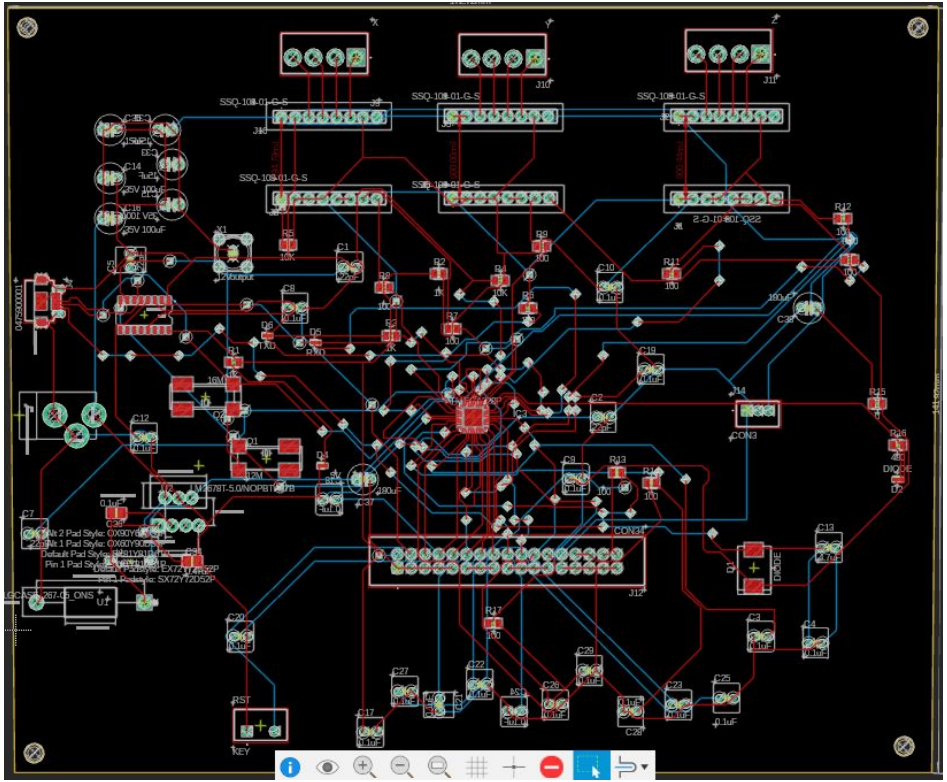
Hardware Design - Overall Schematic



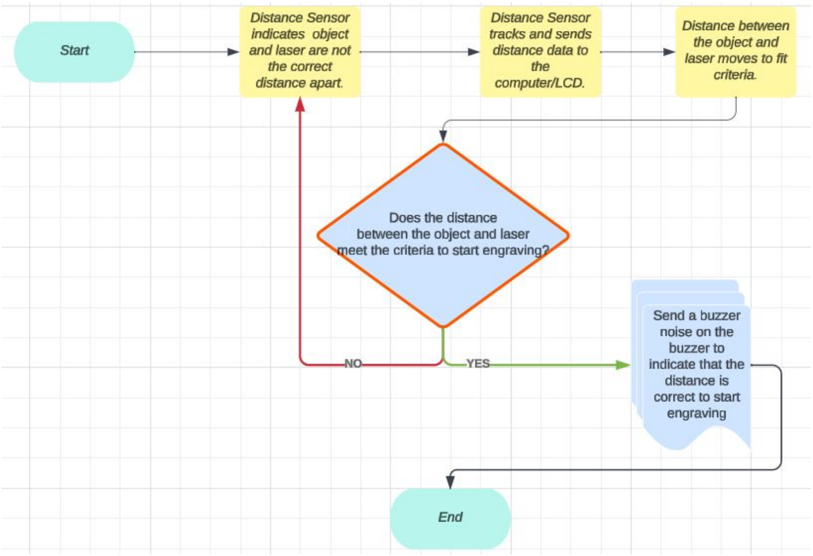
PCB Schematic Design

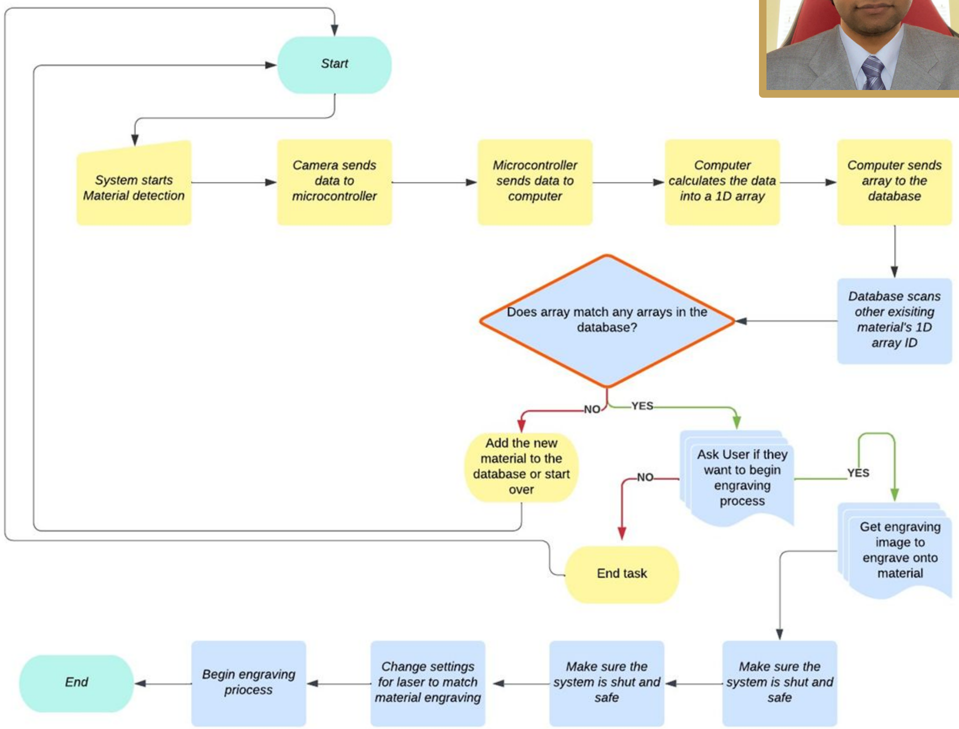


PCB Board Design

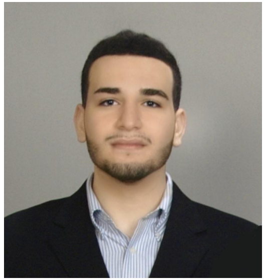


Software Design



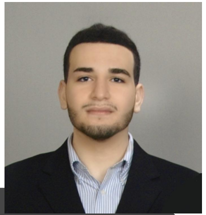


Significance of Mechanical Design



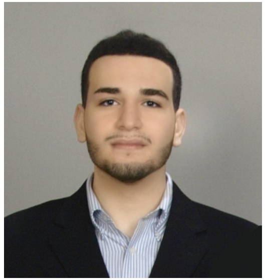
- Mechanical design plays a pivotal role in providing stability, precision, and support for the entire system.
- Ensuring that the mechanical structure, base, and components of the projects are in place as they are needed ensures optimal functionality of the CNC system during the material detection process as well as the laser engraving process.
- Mechanical components form the backbone of the project for achieving its goals and ensuring accurate results from start to finish.

CNC Machine Mechanical Components



Gantry System	Base Structure	Encloser	Z-Height Adjustment System
Role: Facilitates controlled X and Y motions for laser head and spectrometer.	**Role:** Fundamental platform for material support and engraving.	**Role:** Provides a controlled environment for safety and functionality.	**Role:** Enables precise adjustment of the laser tool head's height from the material.
Components: Lightweight yet durable filament materials, POM wheels, Nema 17 stepper motors.	**Material:** High-quality aluminum Extrusion Rails	**Material:** Transparent acrylic or polycarbonate with a tint or complete opaque material	**Components:** Separate Nema 17 stepper motor, lead screw mechanism.
Features: Strategic mounting holes, adjustment slots, reinforced gussets for stability.	**Features:** Dimensional specifications (220mm x 220mm), efficient cooling channels, heat sinks.	**Features:** Viewing window for monitoring, ventilation system with vents and exhaust fans.	**Features:** Automation for accommodating different material thicknesses, integrated sensors.
Design Considerations: Accommodates linear actuators, precise alignment, cable	**Design Considerations:** Ensures stability, uniform heat distribution, and efficient material processing.	**Design Considerations:** Minimizes light interference during material detection, ensures optimal temperature control.	**Design Considerations**: Selection of, DKARDU CNC Router Z-Axis Tool ensures precision and control, contributes to overall system automation.

Gantry System Design

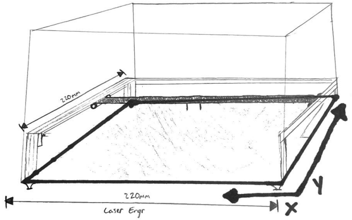


Design Emphasis:

- Rigidity and Stability: Prioritizing a design that minimizes deflection and vibrations during operation.
- Precision: Facilitates precise X and Y motions critical for accurate laser engraving and material detection.

Choice of Materials:

- 80/20 Aluminum Extrusions: Selected for their high strength-to-weight ratio and excellent machinability.
- Advantages: Superior rigidity, corrosion resistance, and adherence to European standard 80/20.
- 6mm Rubber CNC Belts: Ideal for the 80/20 aluminum extrusion cavities for a snug precise fit.
- SIMAX3D CNC POM Wheels: Low noise, high quality, and compatible with our aluminum extrusions.
- Uxcell Aluminum Timing Belt Pulley



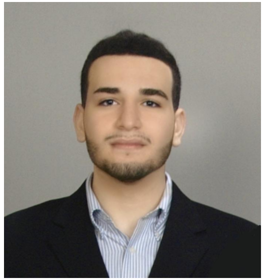
Dimensions:

- Overall Frame Size: Approximately 400x400mm for ample space around the bed.
- Vertical Supports: Strategically placed to provide additional stability and minimize flexing issues during operation.
- Acrylic Cross-Bracing: Potential incorporation for optimal rigidity, preventing unwanted flexing or distortion.

Placement of Nema 17 Stepper Motors:

- *Role:* Responsible for driving linear actuators that effect controlled horizontal motion along the X-axis.
- *Strategic Placement:* Positioned to ensure smooth movement along the Y-axis rails.
- *Adjustment Slots:* Incorporated for accurate positioning, ensuring precise alignment during operation.
- *Cable Management:* Consideration for housing power and signal cables to maintain a tidy workspace.

Enclosure Design



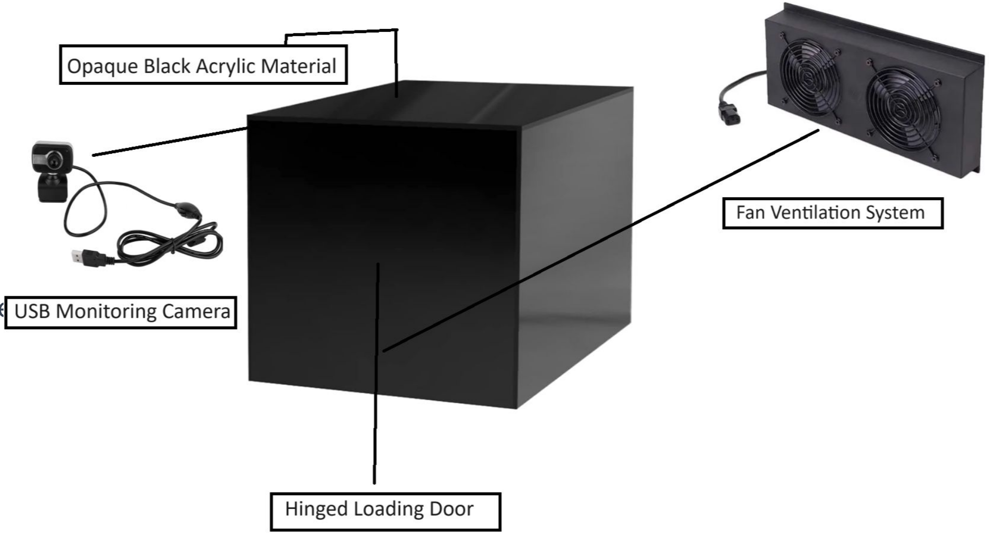
Enclosure Features: Enhancing CNC Environment and Safety

<u>Safety Measures:</u>
- *Containment:* Safely houses laser engraving.
- *User Protection:* Ensures a secure operational environment.

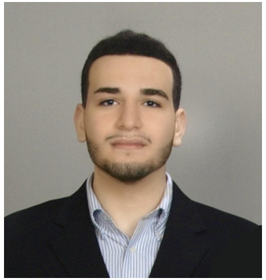
<u>Material Selection: Opaque and Durable:</u>
- *Options:* Black Acrylic or Polycarbonate for both durability and rigidity .
- *Loading Door :* Allows for easy placement and removal of material.

<u>Light Management for Precision:</u>
- *Opaque Enclosure:* Enhances precision in spectroscopic material detection.
- *Monitoring Camera:* Facilitates monitoring in real-time without compromising accuracy.
- *Optical Filter:* 500nm longpass optical filter ensures camera detector will not be saturated with light

<u>Ventilation System:</u>
- *Effective Heat Dissipation:* Maintains optimal temperature for CNC system.
- *Preventing Fluctuations:* Ensures precise material processing conditions.



Z-Height Adjustment System



Z-Height Adjustment System: Precision in Material Control

Importance of Z-Axis Adjustment:

- *Material Thickness Control:* Ensures precise laser focus on various material thicknesses.
- *Enhanced Precision:* Critical for maintaining engraving quality and detail.

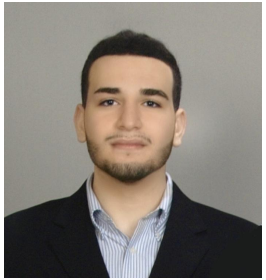
Automated Adjustment System:

- *Stepper Motor Integration:* Nema 17 motor for controlled Z-axis movement.
- *Lead Screw Mechanism:* Converts rotary motion to linear motion for smooth adjustments.
- *Automation Benefits:* Allows for programmability, repeatability, and remote control.

Z-Axis Height Adjustment Sensor Considerations:

- *Ultrasonic Sensor:* Reliable but sensitive to obstacles.
- *ToF (Adafruit VL6180X):* High precision, less affected by external factors.
- *DKARDU CNC Router Z-Axis Tool* ***(Chosen)***

3D Models



- Critical for CNC stability and precision during engraving.
- Facilitates seamless integration of both laser and spectroscopy systems.
- Utilizing SolidWorks for precise 3D modeling.

<u>FDM Printing Material Selection:</u>

- Choosing sturdy and heat-resistant materials for Fused Deposition Modeling or FDM 3D printing.
- Options: High-quality PLA and ABS filaments.

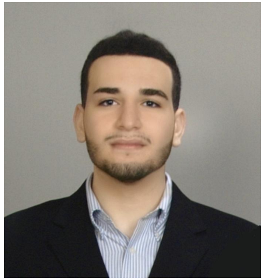
Benefits of Materials Chosen:

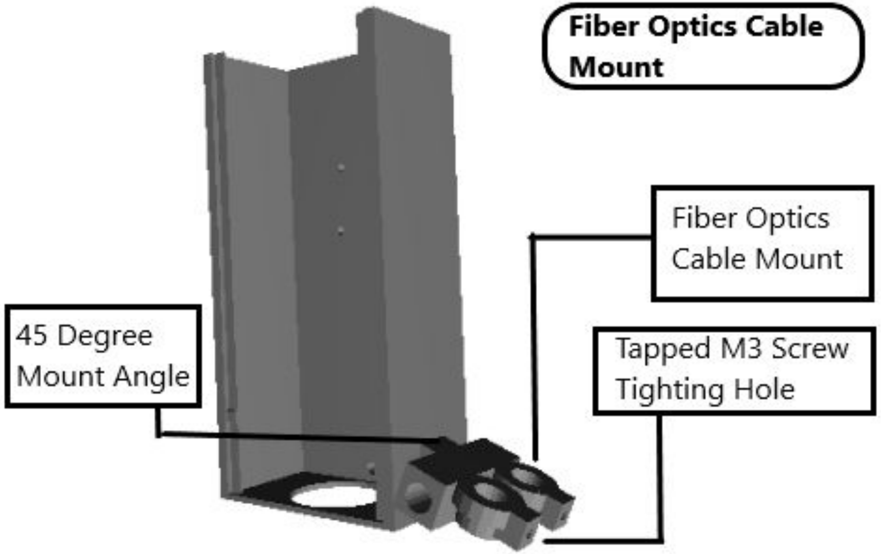
- Polycarbonate (PLA) for high impact and heat resistance, transparency for laser alignment.
- ABS for good mechanical strength, durability, and stability during engraving.

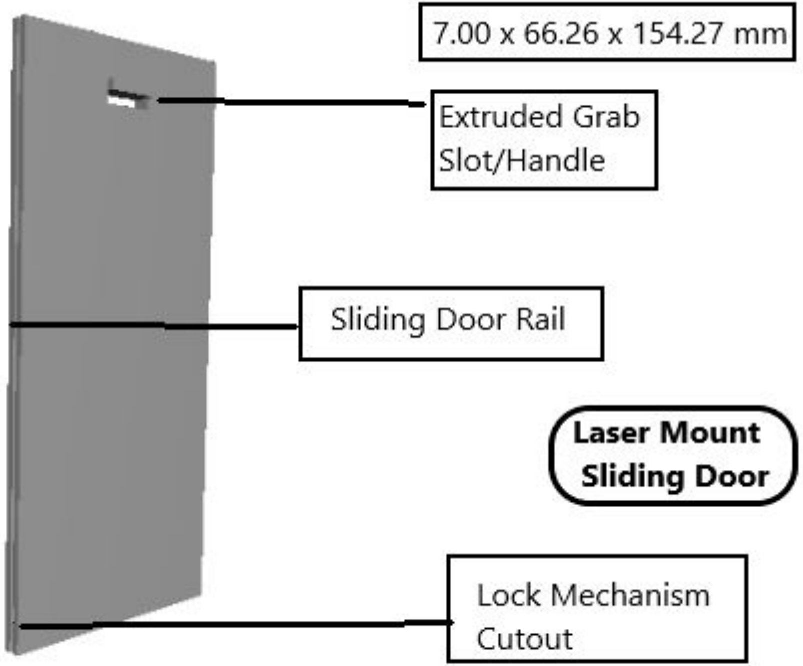
<u>Designed Models:</u>

- ➢ Laser Toolhead Mount with fiber optics cable holster and LED light attachment
- ➢ Gantry X-axis rail tower
- ➢ Spectrometer Housing
- ➢ PCB Housing

Laser Head Mount







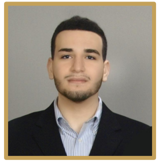
Budget

Discipline	***Component***	***Description***	***Value***
Photonics	Laser Diode	LaserTree 4W 450nm laser diode	$60
Photonics	Focusing Lenses and Mounts	Newport 12.7mm diameter N-BK7 lens with 19mm focal length, LH-0.5A lens mounts	$130
Photonics	Webcam	USB sensor to capture spectral data	$20
Photonics	White LED Light	High powered white LED	<$1
Photonics	Diffraction Grating	600 lines/mm holographic	$25
Photonics	Fiber optic cable	Ocean Optics QP400-2-VIS-NIR	$200, borrowed
Photonics	Optical Filter	500nm Longpass Optical Filter for enclosure camera	$100

Discipline	***Component***	***Description***	***Value***
Computer	Custom PCB	FR-4 PCB with custom design	$30
Computer	Components for PCB	Electronics, IC's required for PCB (BOM)	$50
Computer	GRBL	Software used to program the board	Free
Mechanical	Framing Material	80/20 Aluminum framing material to create the system	$150
Mechanical	Misc	Screws, Bolts, Wires, and other components for assembly	$50

TOTAL ESTIMATED COST: **$616**

Work Distribution

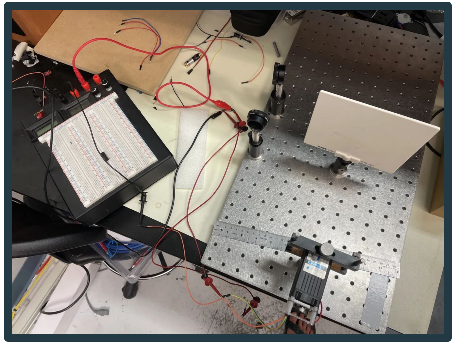
Amir Mohd 	Responsible for mechanical design and assembly of the CNC platform and spectroscopy elements, including the design of custom mounts and mechanisms integrated in the laser engraver design.
Aly Megahed 	Responsible for aiding in PCB design according to the GRBL software, writing Python code for the external computer to parameterise G-code and transmit to CNC controller.
Felipe Mosquera 	Responsible for the creation of a PCB that encompasses the project in power and output, to control the CNC machine to produce engraved images.

Kavinaash Jesurajah 	Responsible for communication between software and hardware and sending data to start engraving process. Spectroscopy system connection with OpenCV and communicating with the system as a whole.
Jackson Gilliland 	Responsible for design and implementation of the laser module and focusing optics, as well as testing laser power and PWM parameters for each engraving material.
Nolan McGinley 	Responsible for the design and construction of the spectroscopy component of the system, entailing the creation of the spectrometer body and the development of the illumination and light capture system for material analysis.

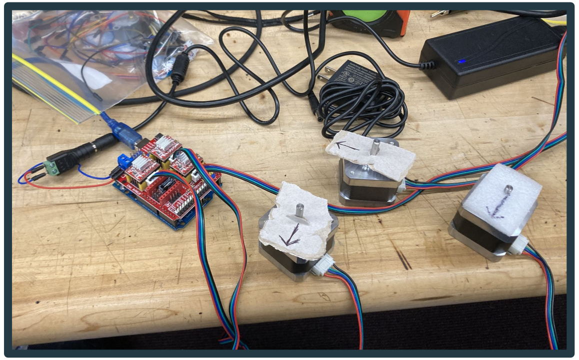
Progress

Spectrometer prototype

Laser module prototype



450nm laser testing



Simultaneous control of X, Y, Z Motors with GRBL + Pulsing Laser with GRBL 1.1