Fabric Laser Cutter System

GROUP 2

CRITICAL DESIGN REVIEW

PROFESSOR SAHAWNEH

Group Members

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Goals and Objectives

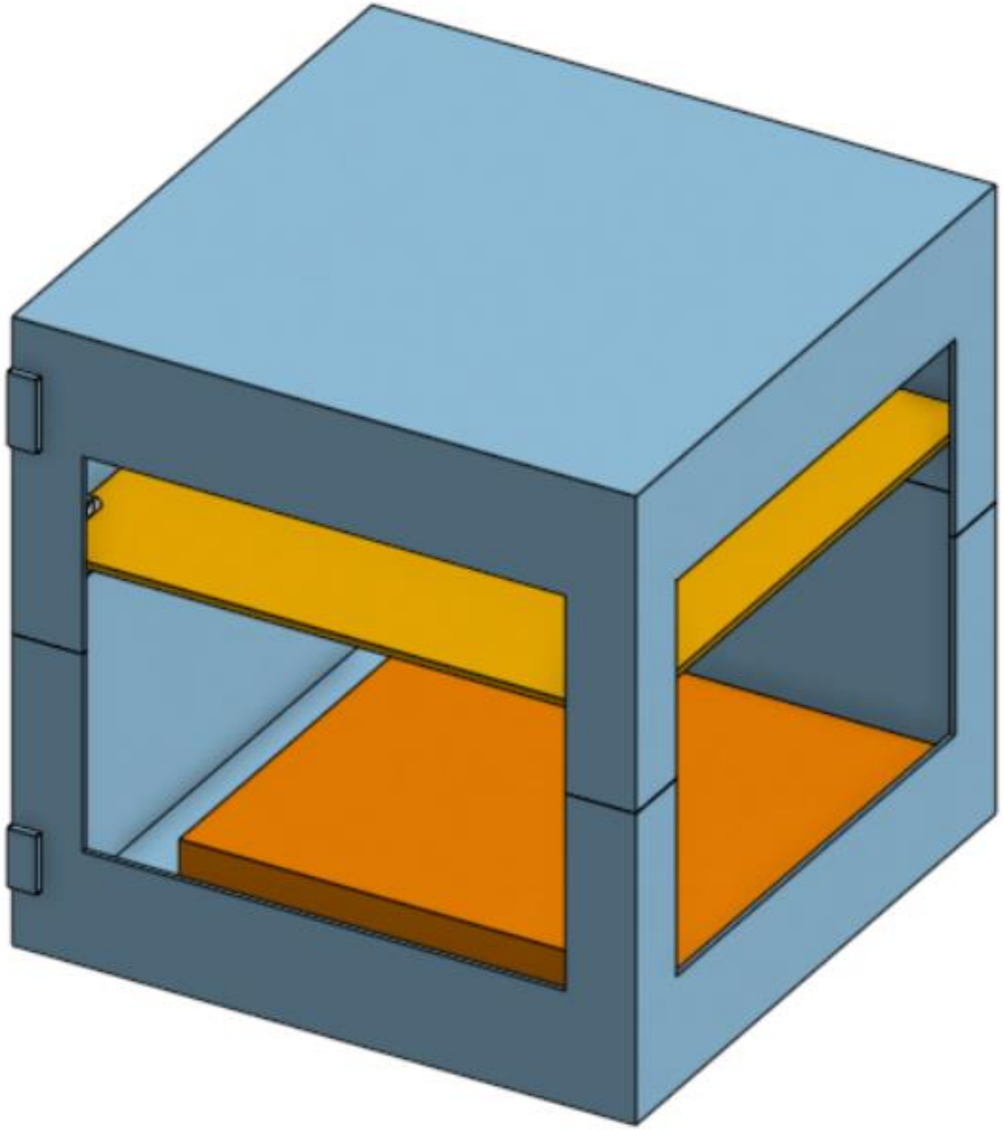
- Safe and Easy to use
  - Human Machine Interface (HMI) Touchscreen with clear, understandable options
- Cuts target lines accurately and safely
  - Lens system delivers the beam with kerf width size less than half a millimeter
  - X-Y moving gantry with mirror system
  - Photodiodes will monitor back reflection and adjust laser output power accordingly
- Identify lines to be cut on multiple types of fabric
  - Image acquisition system identifies lines drawn on fabric
  - Adjustable focus lens

Motivation and background

- Make fabric cutting easier
  - No computer software or file upload is needed
  - For those without knowledge of traditional laser cutting software
- Useful for hobbyists, designers, and manufacturers

Existing Projects

- Commercial Laser Engravers
  - Laser is not stationary and moves using gantry system
  - Wattsan 6090 LT [1]
- Automated Parameter Adjusting Laser Engraving System- Group 5 Senior Design F23-S24555 [2]
  - Similar to our system but with the goal of engraving different materials
  - Features a spectrometer system
  - 6-person group



3D Model

- Enclosure (Blue)
- Laser Cut Platform (Yellow)
- Gantry System and Honeycomb Laser Bed (Orange)
- Windows are OD6 rated
    - Meaning no laser light can escape the enclosure

Engineering Specifications

Specifications	
Image acquisition processing time	~500 milliseconds
Laser redirection speed	10 Millimeters per second, depends on fabric type and thickness
The system shall provide user feedback on errors and job progression	≥90% of errors produce an onscreen message
Screen Resolution	720 x 1280 pixels
HMI Boot Time	≤35 seconds

Optical Engineering Specifications

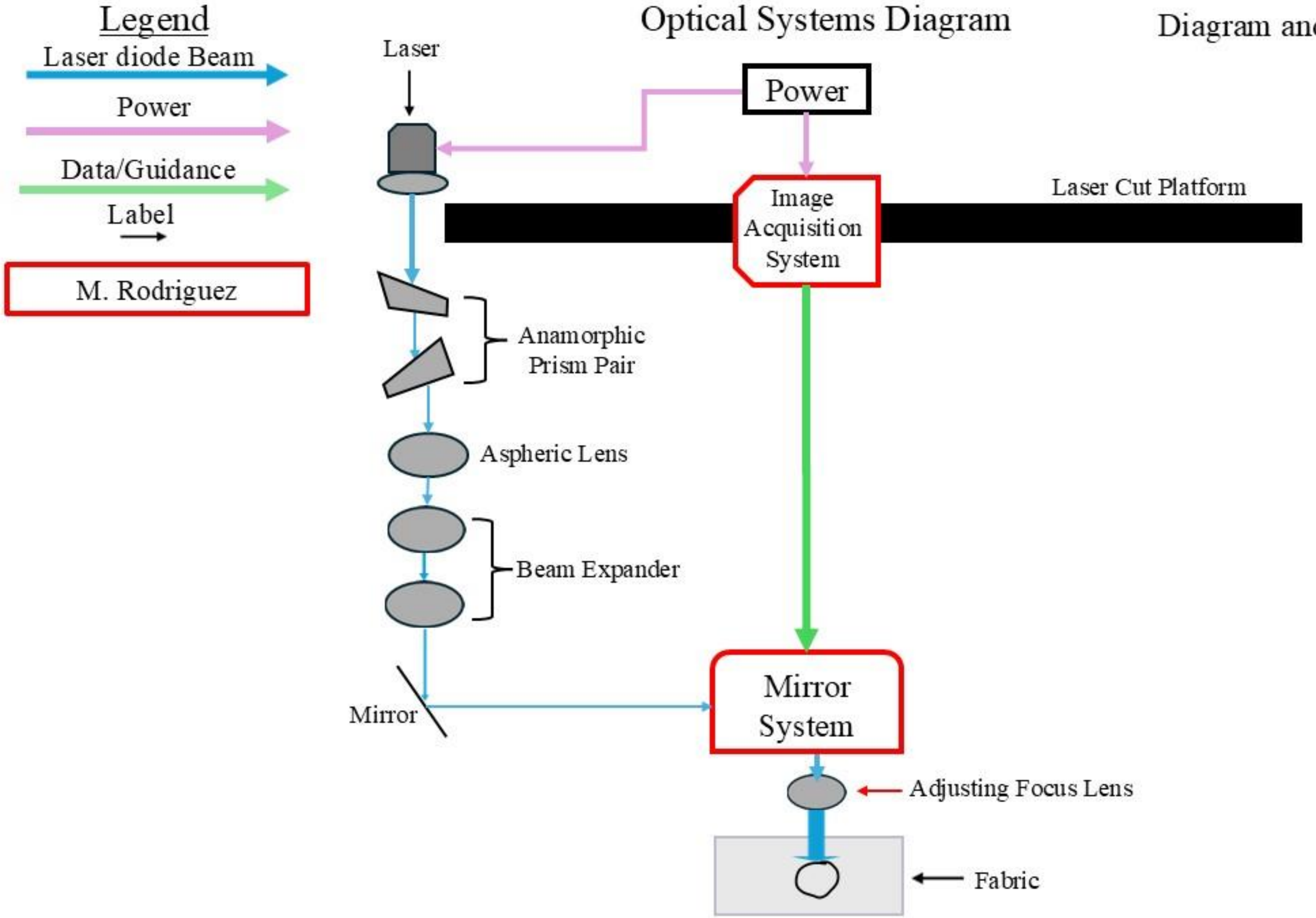
Specifications	
Final spot size on fabric	<100 microns
Camera Height from Fabric	~330 millimeters
Laser Wavelength	455 nanometers
Beam expansion prior to mirrors	7-8x
Mirror Reflectance	>99%
Reliably detect reflections with powers of up to	5 watts

Optical System Components

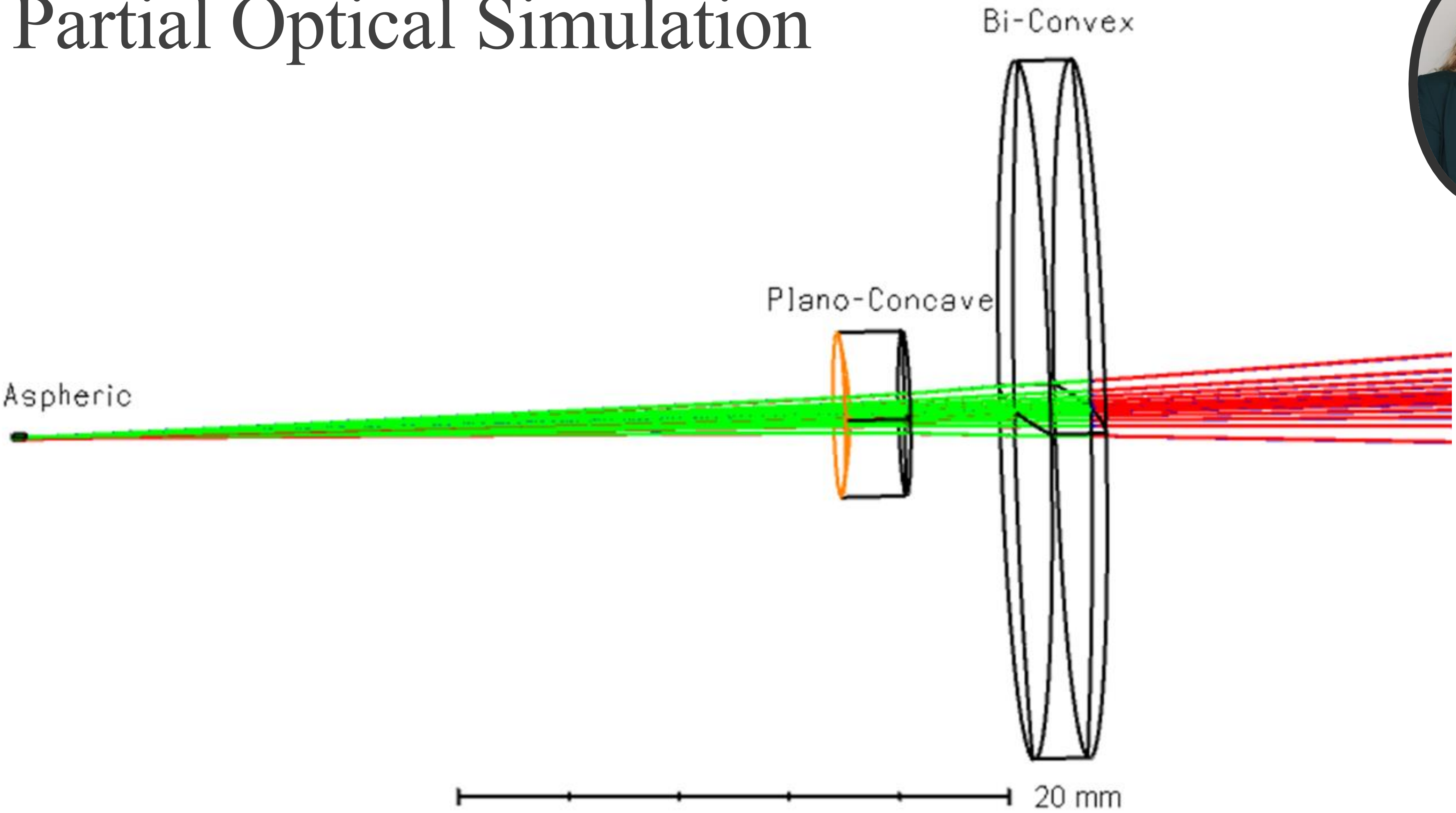
	Beam Shaping Optics			Beam Expander Lens 1 (Plano-Concave Lens)		Beam Expander Lens 2 (Convex Lens)	
Component	Anamorphic Prism Pair Thorlabs PS873-A	Aspheric Lens Thorlabs C719TMD-A	Aspheric Lens Thorlabs C140TMD-A	Thorlabs LA6002	Thorlabs LC1975	Thorlabs Bi-Convex lens LB1945-AB	Thorlabs Plano-Convex Lens LA1613
Specifications Focal Length(mm) Design Wavelength(nm) Cost (USD)	N/A 405 203	1.5 1550 112	1.5 780 104	45 465 387.66	-25.4 587 28.72	198.4 587.6 45	149.8 587.6 29

Optical Systems Diagram

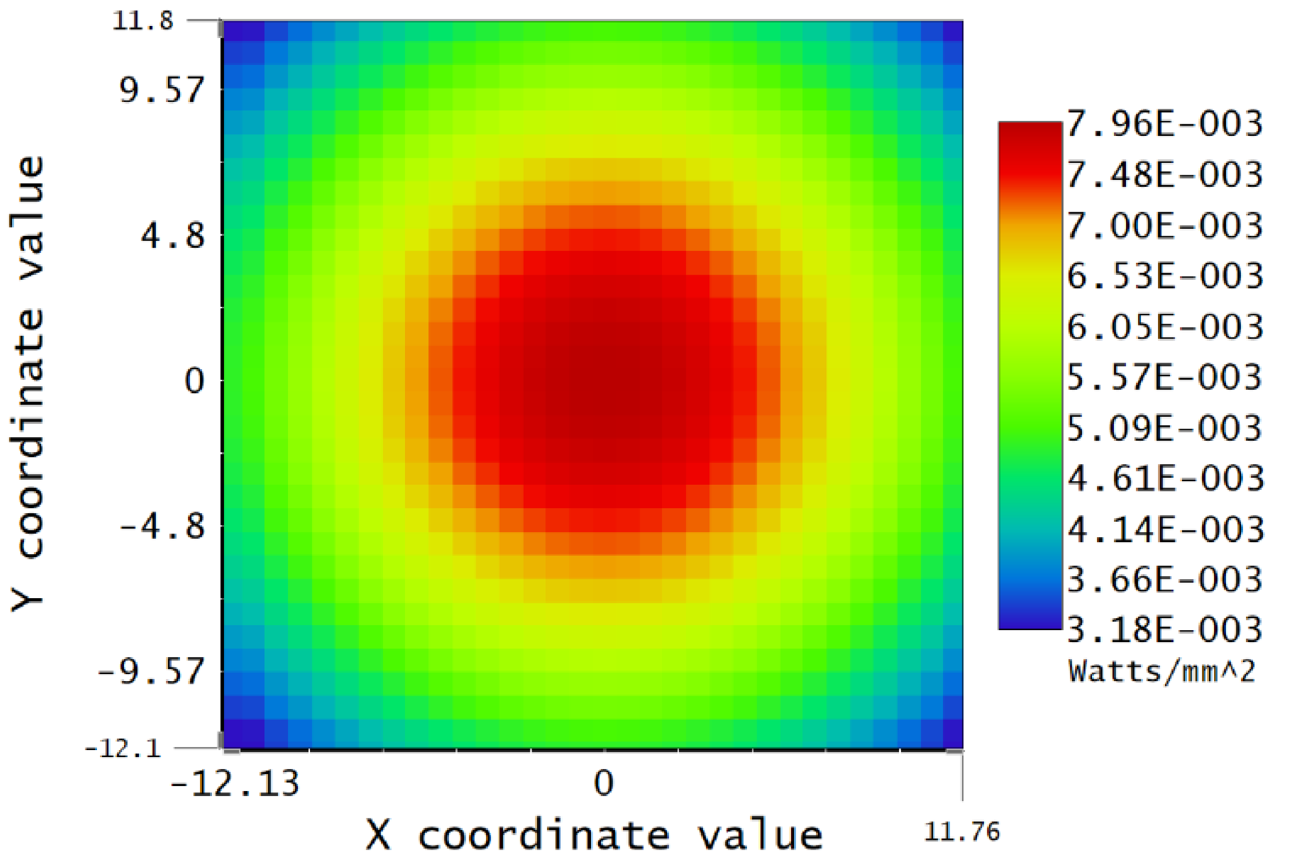
Diagram and System by J. Harper



Partial Optical Simulation



Partial Optical Simulation



Total Irradiance surface 7

10/30/2025
Beam wavelength is 0.45500 µm in the media with index 1.00000 at 0.0000, 0.0000 (deg)
Display X Width = 2.4548E+01, Y Height = 2.4548E+01 Millimeters
Peak Irradiance = 7.9604E-03 Watts/Millimeters^2, Total Power = 3.5000E+00 Watts
Pilot: Size= 2.4549E+01, Waist= 1.0159E-03, Pos= 1.7220E+02, Rayleigh= 7.1262E-03
Beam Width X = 1.32376E+01, Y = 1.32376E+01 Millimeters

- Demonstrates maximum width of 13.2 millimeters
- Maximum wattage of 7.96 milliwatts per mm²
  - Not completely accurate as it does not take into account our laser power
- Using Irradiance equation below

$$Irradiance = \frac{4P}{\pi d^2}$$

  - Maximum Irradiance = 58µW

Optical System Testing

Hardware Comparison: Mirrors

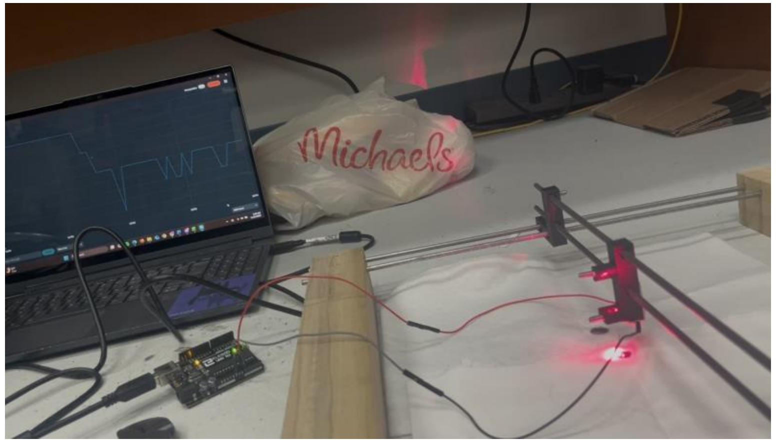
Specifications	Fused Silica Broadband Dielectric (E02)	Protected Silver	Protected Aluminum
Reflectivity (455 nm)	>99%	>97%	>90%
Bandwidth	Moderately broad 400nm - 750nm	Very broad 450 nm - 2 µm	Very broad 450 nm - 2 µm
Absorption	<1%	<3%	<10%
Laser Damage Threshold	High threshold (470 W/cm)	Moderate threshold (213 W/cm)	Low threshold, lot of power absorbed (43 W/cm)
Surface Quality	High quality, laser-grade, low scatter (10-5 Scratch-Dig)	Good quality, good for optics (40-20 Scratch-Dig)	Good quality, good for optics (40-20 Scratch-Dig)
Cost	Most expensive $50	Least expensive ~$30	Moderately expensive ~$40

Hardware Comparison: Pi Cameras

Specifications	Camera Module 3	Camera Module 3 Wide
Sensor Resolution	4608 × 2592 pixels	4608 × 2592 pixels
Focus	Motorized	Motorized
Weight	4g	4g
Depth of Field	10 cm+, larger range of focus	5 cm+, shorter range of focus
Horizontal Field of View	66 degrees	102 degrees, image distorted at the edges
Vertical Field of View	48.8 degrees	67 degrees, image distorted at the edges
Price	$25	$35

Hardware Comparison: Photodiodes

Specifications	BPW34	VTB8440BH	PDB-C152SM
Peak Wavelength	900 nm	580 nm	900 nm
Spectral Bandwidth	430 nm – 1100 nm	330 nm – 720 nm	400 nm – 1100 nm
Responsivity (455 nm)	0.083 A/W	0.25 A/W	0.1 A/W
Power Dissipation	215 mW	250 mW	125 mW
Packaging	Plastic	Ceramic/Glass	Plastic
Active Area	7.5 mm^2	5.16 mm^2	1.66 mm^2
Price	$1	$3	$2

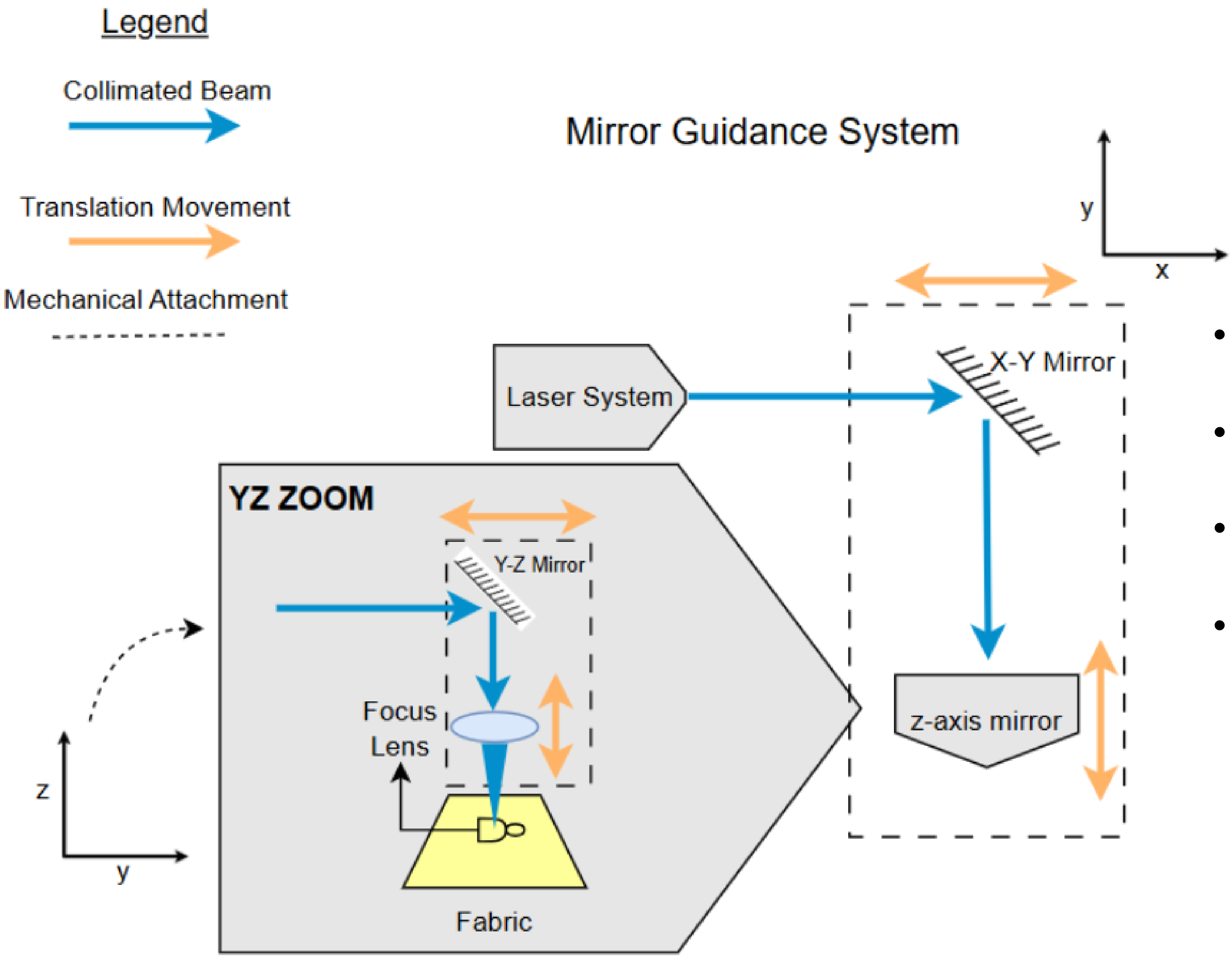


Demonstration of a BPW34 photodiode detecting scattered reflections from a red test laser. The voltage reading significantly drops when beam is moved from the white fabric onto the black spot.

- Due to the high power of the laser, an ND filter of at least ND100 would need to be placed over the photodiodes to prevent oversaturation and damage.
- Opting for simple series resistor instead of TIA design.

Hardware Comparison: Focus Lens

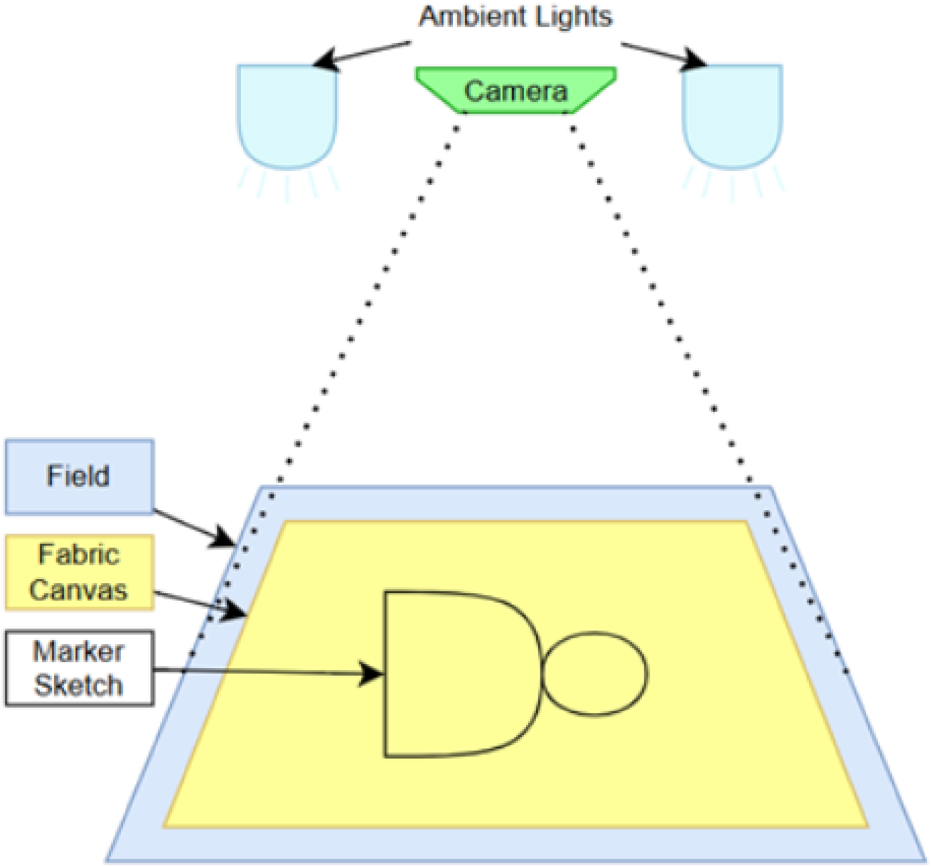
Specifications	Plano-Convex (LA1074-A)	Bi-Convex (LB1212-A)	Aspheric (354280-A)
Effective Focal Length (455 nm)	19.6 mm	19.6 mm	17.9 mm
Coating	AR Coating (350 nm – 700 nm)	AR Coating (350 nm – 700 nm)	AR Coating (350 nm – 700 nm)
Spot Diameter at Focal Point (455 nm)	313.324 μm (aberration-limited)	146.354 μm (aberration-limited)	3.608 μm (diffraction limited)
Lens Diameter	12.7 mm	9 mm	6.5 mm
Price	$39.10	$38.77	$83.90



Mirror Guiding System

- Two mirrors attached to the gantry direct the beam
- The mirrors independently in X and Y directions
- After the final mirror, a lens focuses the beam to a small spot on the fabric
- Lens height is adjusted based on the fabric thickness or user

Camera Setup

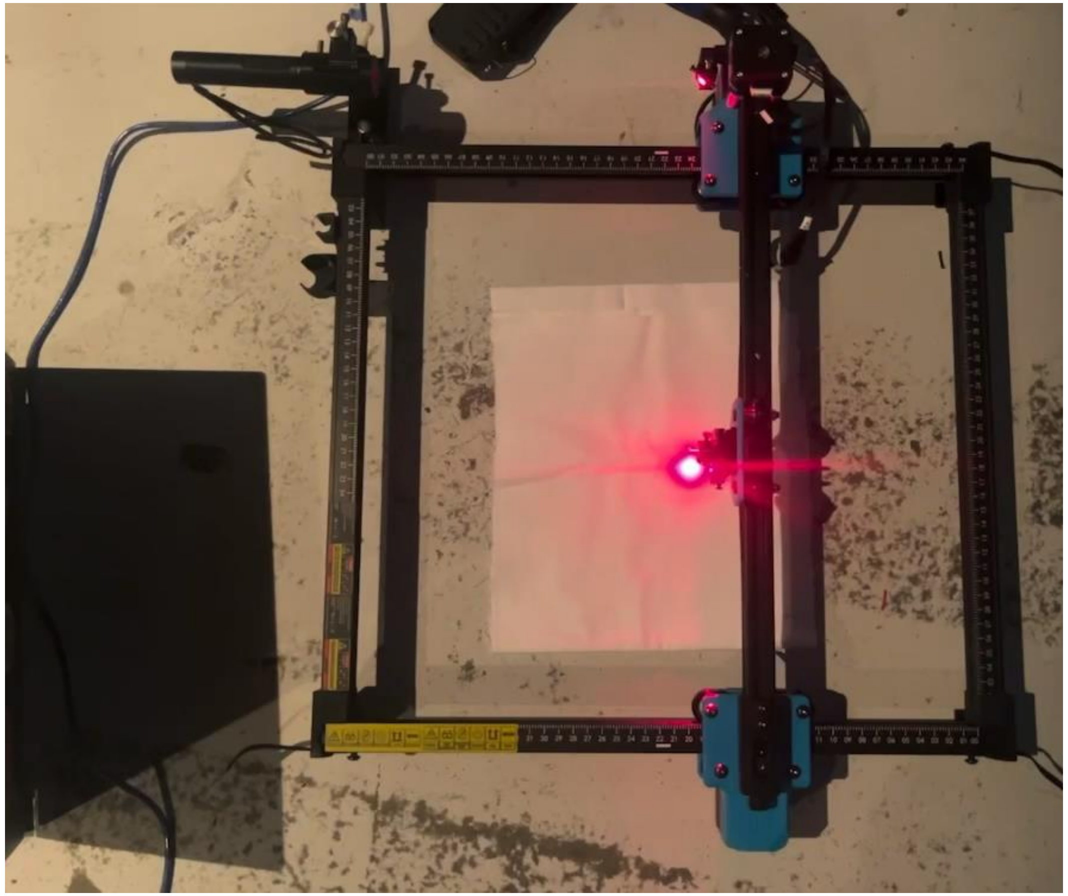


- Camera will be set at a height where the entire field area (300mm x 300mm) takes up the camera frame with minimal external areas visible.
- The gantry will move out of the way and ambient lights on so that the camera can take a clear snapshot of the fabric.

$$\frac{300mm}{2\tan(\frac{48.8°\ FOV}{2})} = 330.7mm\ height$$

- The snapshot is then sent to the Raspberry Pi for image processing and analysis.

Mirror Guiding Prototype

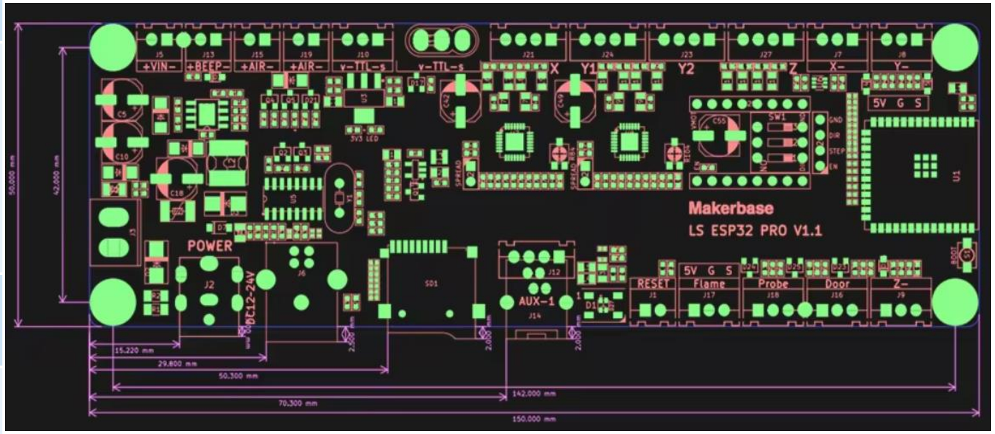


- Using low-power red laser for demonstration
- Mirrors and laser were aligned before the job
- Beam center shifts minimally, but stays continuously reflected onto the fabric
- Output is incredibly sensitive to movement and vibrations

Electrical PCB Alternative

- We were allowed to purchase a pre-built CNC laser engraver and modify it to suit our needs.

Includes
Makerbase MKS LS ESP32 PRO V1.1 Motherboard • ESP32 dual-core 32-bit CPU • Multitude of ports for additional motors, UART, sensing, etc. • Wi-Fi and Bluetooth capabilities • Compatible with laser engraver software such as LaserGRBL and LightBurn
Laser Module • 455 nm wavelength • 5.5 W max optical power • Adjustable average output power by PWM signal
3x NEMA17 motors (2 for the crane and 1 for the carriage)
Belt driven gantry



Motherboard Schematic

Power Distribution Table

Component	Voltage	Current Draw
Raspberry Pi 4b	5 V	3 A
Touch Display	5 V	600 mA
Raspberry Pi Camera v3	3.3 V	400 mA
Engraver	12 V	8 A
NEMA11 Stepper Motor	3.3 V	800 mA
Photodiode	5V	Variable µA

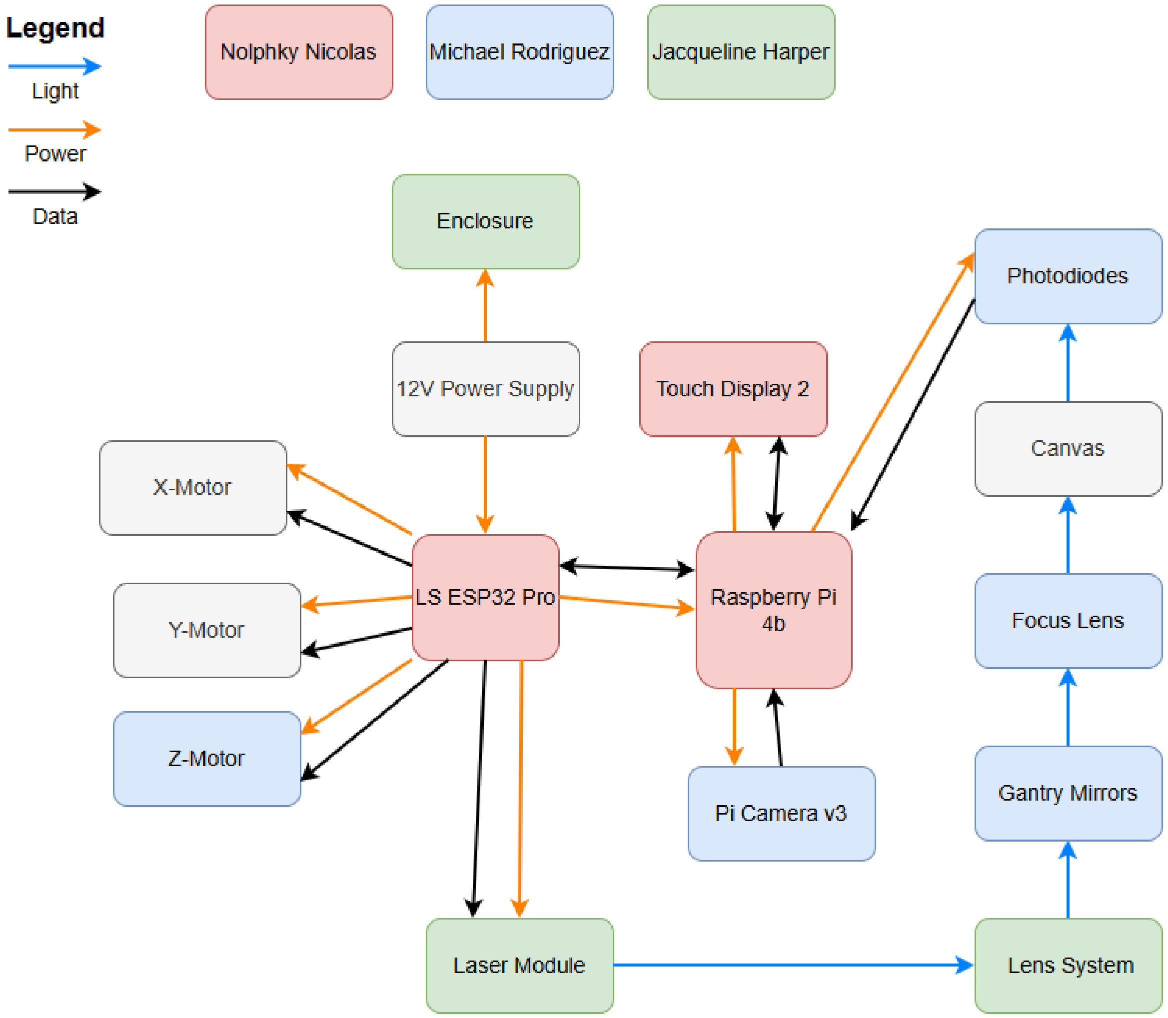
Hardware Comparison: Main Controller

	Raspberry Pi 4B	Raspberry Pi 5	Arduino Mega 2560 Rev3	Nvidia Jetson Nano	ESP32-WROOM
Ram	4GB LPDDR4 SDRAM	4GB LPDDR4X-4267 SDRAM	8kb SRAM	4GB 64-bit LPDDR4	520kb SRAM, 4MB flash
Processor	Broadcom BCM2711, a Quad-core Cortex-A72	Broadcom BCM2712, a Quad-core 2.4GHz Arm Cortex-A76	ATmega2560	Quad-core ARM Cortex-A57	Xtensa LX6
Power Requirement	5V 3A	5V 5A	7 – 12V or regulated 5V	5V 4A	3.3V 240mA
Cost	$55	$60 - $80	$35 - $45	$130 - $180	$4 - $15

Hardware Comparison: Touchscreen

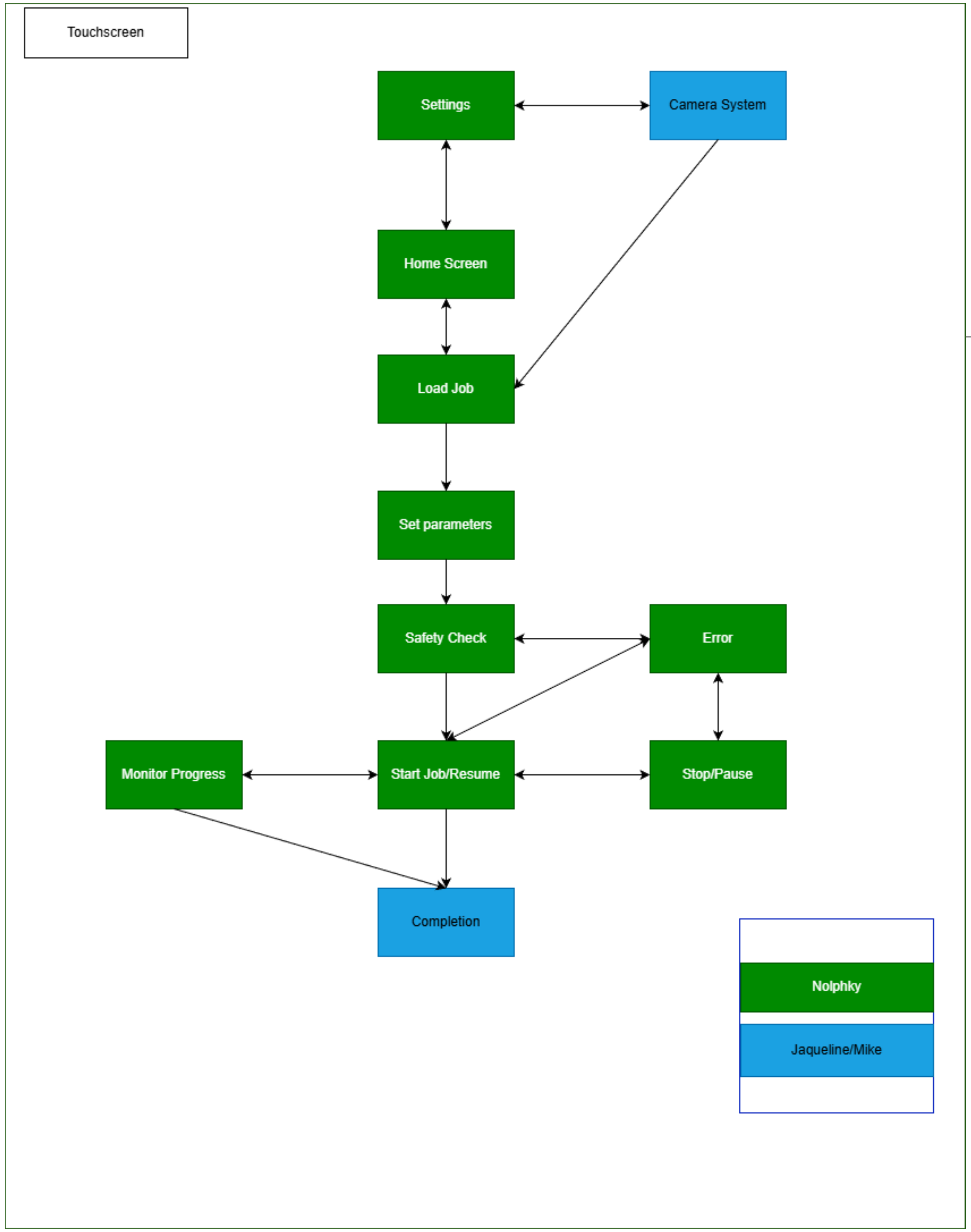
	Raspberry Pi Touch Display 2	Generic 7” HDMI touchscreen	10.1” HDMI Touchscreen
Resolution	720x1080	1024x600	1280x800
Size	7"	7"	10.1"
Touch spec	Capacitive 5-touch	(5-10 touch)	(5-10touch)
Connection to pi	DSI ribbon (video) + 5 V GPIO (power/touch)	HDMI (video) + USB (touch) + 5 V barrel/USB (power)	HDMI (video) + USB (touch) + 5 V barrel/USB (power)
Power draw	~2.4-3 W	~3-5W	~5-8W
Cost	~$80	~40-70	~$80-130

Hardware Block Diagram



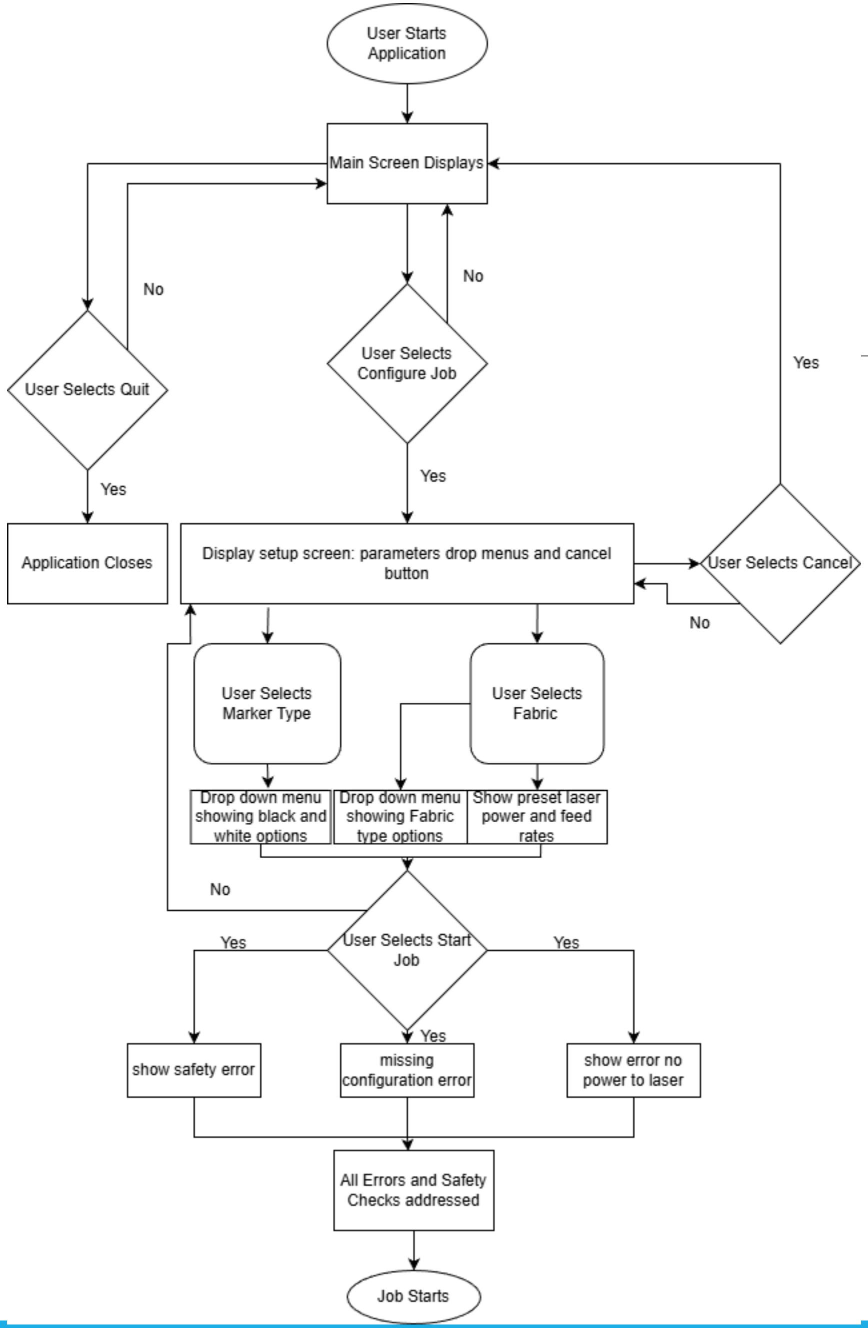
Software Comparisons

	Python	C/C++
Pros	• Rapid development and fast iteration • Extensive libraries (OpenCV, NumPy, Tkinter, serial) • High readability and maintainability	• Compiled language with deterministic timing • Minimal memory overhead • Suitable for real-time embedded systems
Cons	• Interpreted language leading to slower execution speed • Less deterministic timing • Higher memory usage	• More complex syntax • Manual memory management • Increased risk of low-level bugs
Fit for Project	Selected for Raspberry Pi HMI implementation, and camera processing	selected for microcontroller firmware (motion control, PWM laser modulation, safety interlocks ect)



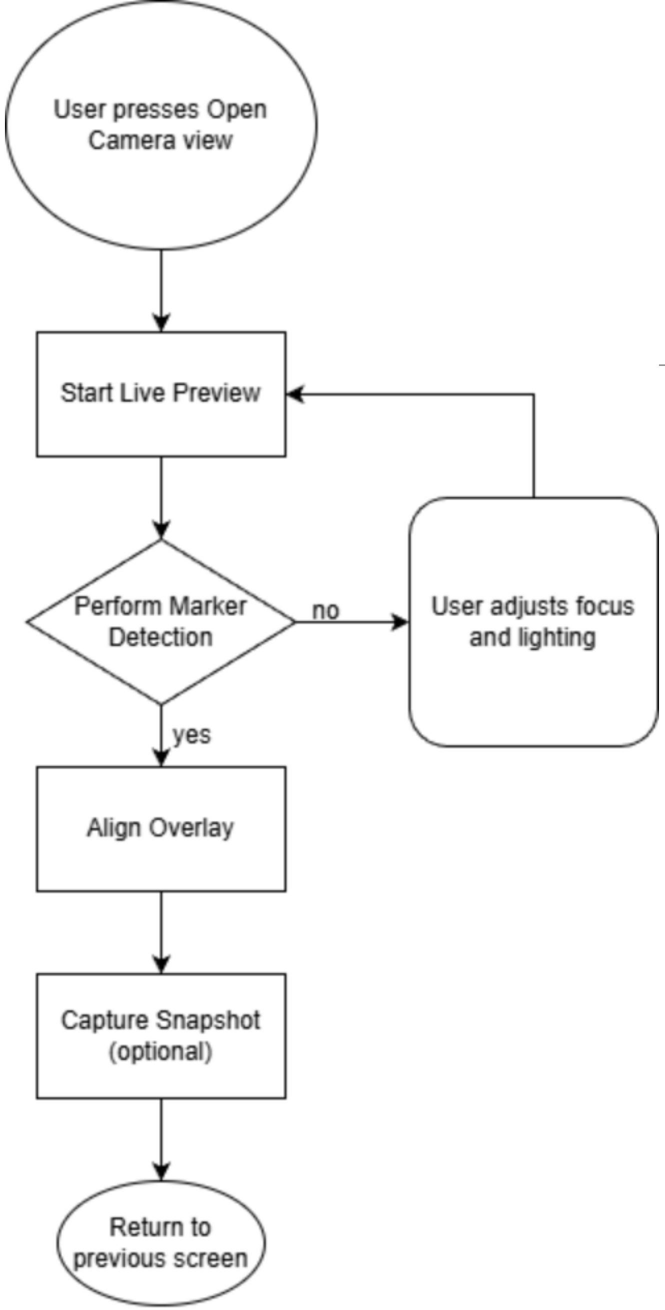
Software Flowchart

The Software is intended to be simple and easily navigable by anyone using the machine.



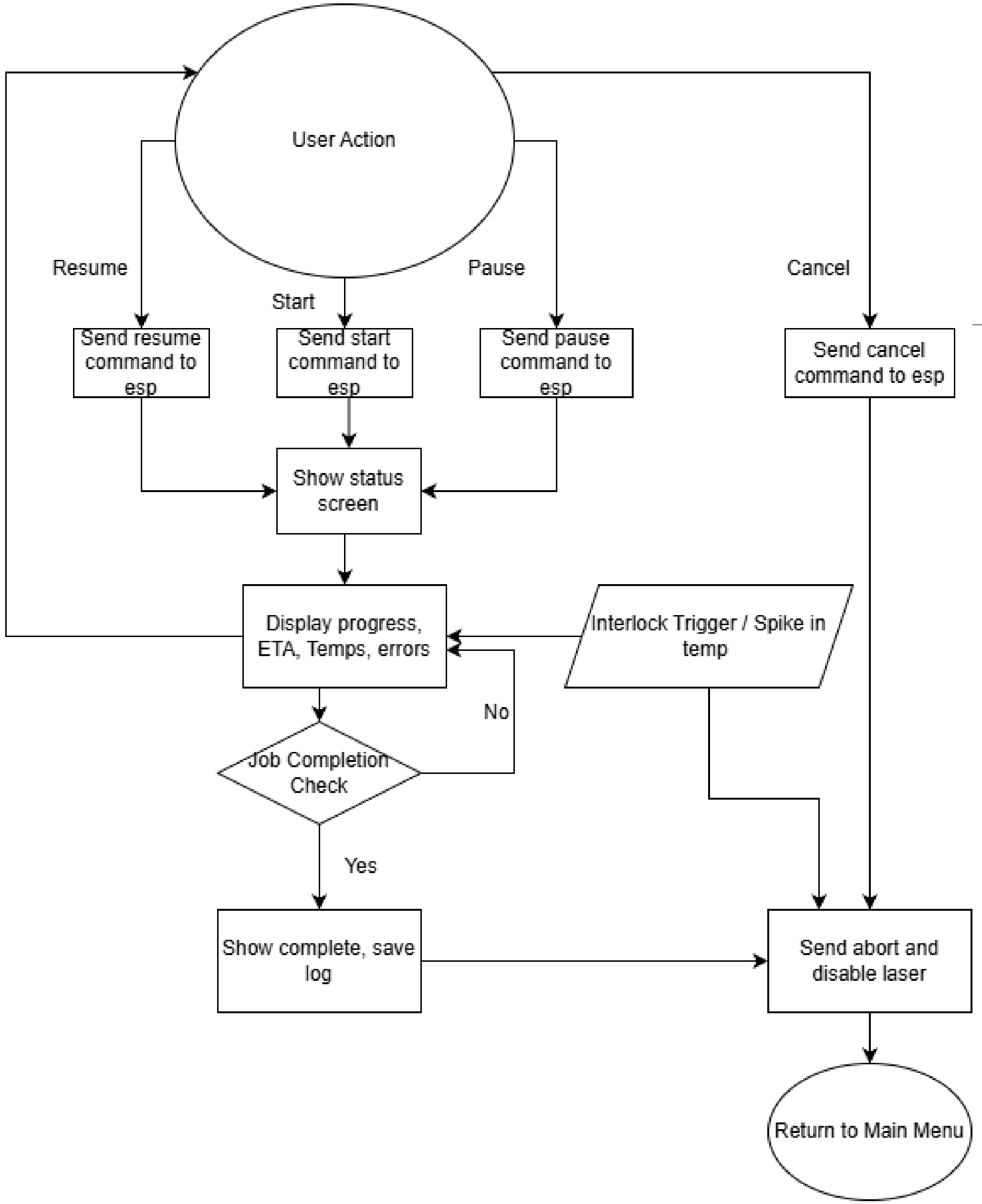
Software Flowchart Continued

The image to the left demonstrates the software logic for initiating a laser cutting job through the UI



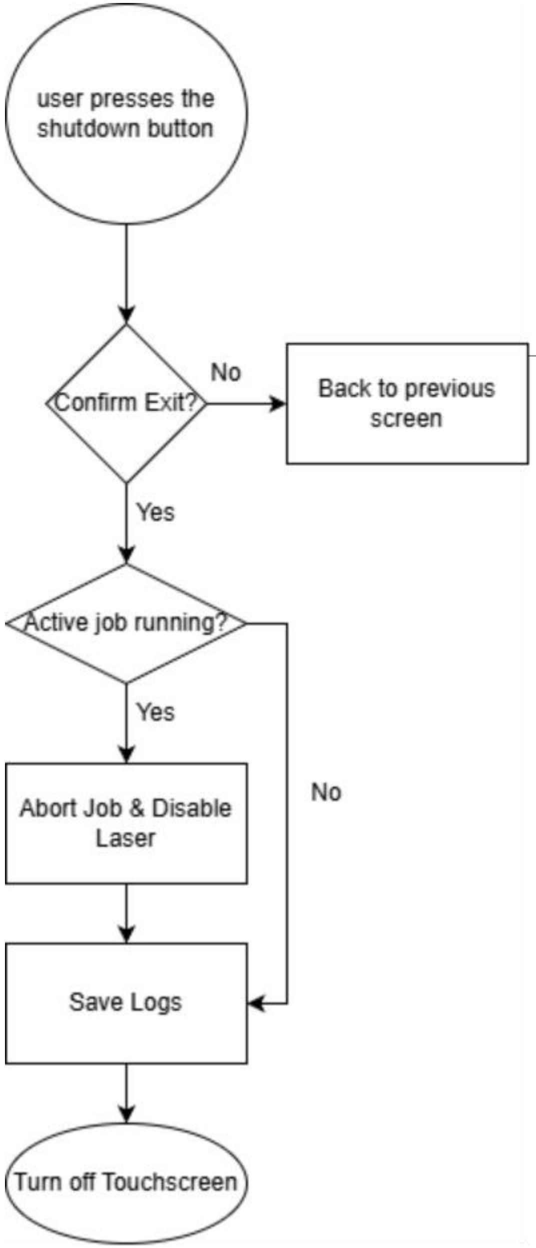
Software Flowchart: Camera

The figure to the left illustrates the automated marker detection section of the touchscreen interface



Software Flowchart: Job Monitoring

The figure to the left shows the logic implemented for job monitoring and safety management.



Software Flowchart: Shutdown

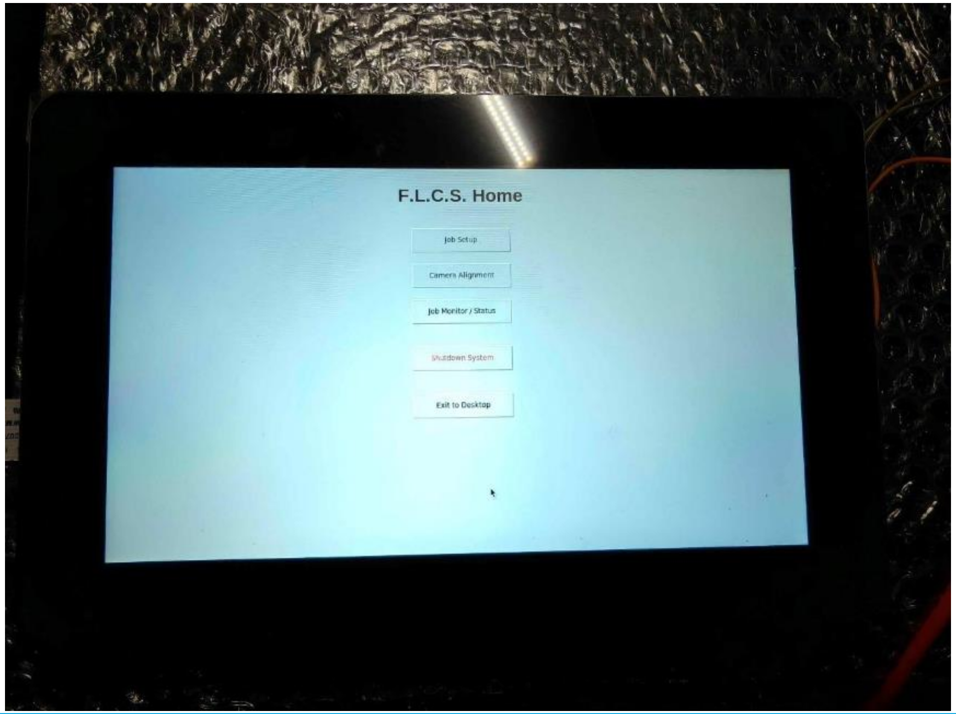
The flowchart to the left illustrates the shutdown routine for the touchscreen interface.

Prototype and Testing : Touchscreen

The Raspberry Pi Touch Display 2 was connected to the Raspberry Pi 4B using the MIPI-DSI ribbon cable that came with the latter and powered using the 5 V and GND pins on the Pi’s 40-pin header.

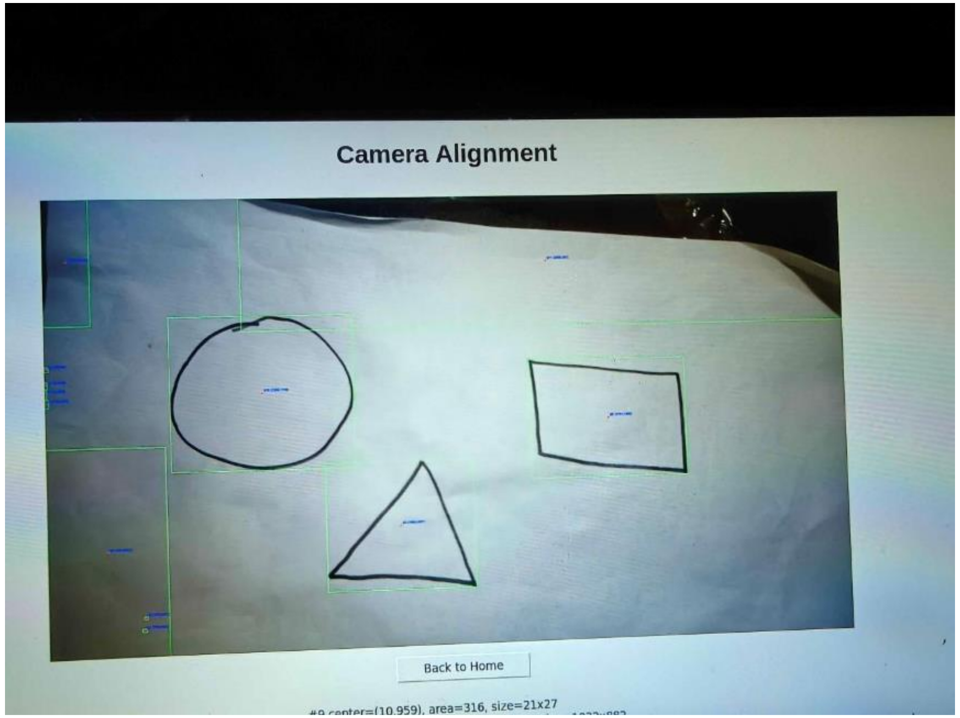
Prototype and Testing: HMI

The current prototype of the HMI is a python-based full screen application that also includes an on-screen shutdown button intended for operator use at the end of a job.



Prototype and Testing: HMI

The goal of the subsequent tests is to verify that the UI launches reliably, responds correctly to touch input, launch the prototype python code from the camera alignment page, and triggers a clean system shutdown when requested by the user.



Problems and Future Work

Current system Limitations:

- Bounding box Detection
  - System currently performs region-based object detection and outputs rectangular bounding boxes only
  - Does not extract the true contour of the marker trace which is not sufficient for accurate G-code path generation

- Future Work and Solutions:
  - Securing laser on the platform as well as the optical system on the enclosure
  - Image processing such as grayscale conversion and noise filtering
  - Edge detection and contour extraction

Budget and Bill of Materials

Bought By:	Item:	Details:	Quantity:	Total Price(USD)
Mike	Raspberry Pi 4/4GB	Main processor for touchscreen HMI and image processing	1	55
Mike	Sandisk ImageMate Pro (64GB)	Storage for Raspberry Pi	1	15
Nick	Respberry Pi Touch Display 2	Main Touchscreen	1	99.07
Nick	Dofiki Honeycomb Laser Bed	Protective layer that minimizes contact between the fabric and enclosure	1	42.79
Jacqui	Aspheric Lens	Collimates beam	1	104.30
Jacqui	Anamorphic Prism Pair	Shapes the beam	1	202.10
Jacqui	Beam Expansion Lenses (2)	Expand and nearly collimate beam	1	72.00
Mike	Dielectric Mirrors	Redirects laser beam	3	150.00
Mike	Aspheric Focusing Lens	Focuses laser beam onto fabric	1	84.00
Jacqui	Enclosure	Houses system with OD6 Protection	1	180.00
Everyone	Laser Engraver System	Provides motherboard and gantry system	1	180.00

Work Distribution

Jacqueline Harper (PSE)	• Group Lead: Facilitating meetings, setting deadlines, deliverable document formatting, encouraging time management • Project Motivation and Background • Laser system with beam shaping and expansion lens system • 3D Model and mounts to properly secure components • Housing selection and laser system integration
Michael Rodriguez (PSE)	• Mirror guiding system • Final lens focusing onto fabric • Image acquisition and gantry path generation • Photodiodes for scattered beam light detection
Nolphky Nicolas (CPE)	• System Software Integration • HMI interface

References

1) “Wattsan 6090 LT”. *Wattsan*, https://wattsan.com/product/wattsan-6090-lt/?srsltid=AfmBOory9nmu9Siww-hZrptmbuj_zTc-xi6FvI4JbPgQV08FTDa5Ga4x.

2) Felipe Mosquera, A. M., Kavinaash Jesurajah, Jackson Gilliland, Nolan McGinley, Amir Mohd (2024). "UCF Senior Design Group 5 Fall 2023 - Spring 2024." from https://www.ece.ucf.edu/seniordesign/fa2023sp2024/g05/.