Fabric Laser Cutting System (F.L.C.S)

Group 2

Final Presentation

Professor Sahawneh and Professor Kar

Group Members

Jacqueline Harper
Photonic Science and Engineering

Michael Rodriguez
Photonic Science and Engineering

Nolphky Nicolas
Computer Engineering

Basic Goals

- Laser beam cuts through fabric with kerf size of less than .5 millimeters
- Beam from the laser diode is delivered to mirrors safely, and later the fabric
- Human Machine Interface (HMI) boots with a functional, intuitive user interface
- HMI clearly display operational options and system status
- HMI clearly display job progress
- Touchscreen shall be secure through brackets that prevents loosening or flex
- Touchscreen boots directly into a functional user interface without manual login or terminal interaction
- Touchscreen options are clear and understandable to the user
- Capture back-reflections from the fabric
- Confidently identify marker on fabric canvas
- Capture clear image of entire fabric canvas in the frame
- Beam can cleanly cut through fabric
- Mirror system guides laser beam to target precisely

Advanced Goals

- Beam is minimized by >4x before reaching mirrors
- Nearly collimated beam before contacting mirrors
- HMI displays real time job preview from the camera
- HMI displays descriptive error messages for user diagnostic
- Include buzzer or speaker for events such as job completion or system errors
- Confidently identify shapes on multiple fabric types
- Identify sketches from multiple marker colors
- Generate coordinate points from capture for smooth operation

Stretch Goals

- Sensor system integration that can identify reflectance and corresponding required passes for the fabric
- Adjust power to account for different types of fabrics
- Support job file upload via USB or wireless transfer
- Log previous job parameters and error history for diagnostics
- Integrate with a companion app for remote job upload and monitoring
- Adjustable power/speed for differing thicknesses of fabric

Objectives

- **Basic**
  - Fused silica dielectric mirrors used to reflect 99% beam light
  - X-Y moving gantry moves the components redirecting the beam; accurately redirecting the spot on the fabric
  - Maintain maximum intensity on the fabric at any point with accurately aligned optical mounts
  - Camera is placed at a height of 330mm above the gantry to give a working area within the 300mmx300mm gantry area
  - The Raspberry Pi Display 2 boots and launches the laser-cutter UI automatically through a kiosk-mode configuration within 30 seconds of powering on and will be fully interactable with the user
  - Design the touchscreen UI layout with clearly labelled and user-friendly icons, consistent color coding, and font sizes
  - Markings on fabric can be identified accurately using a Pi Camera 3 and a Raspberry pi

Objectives Continued

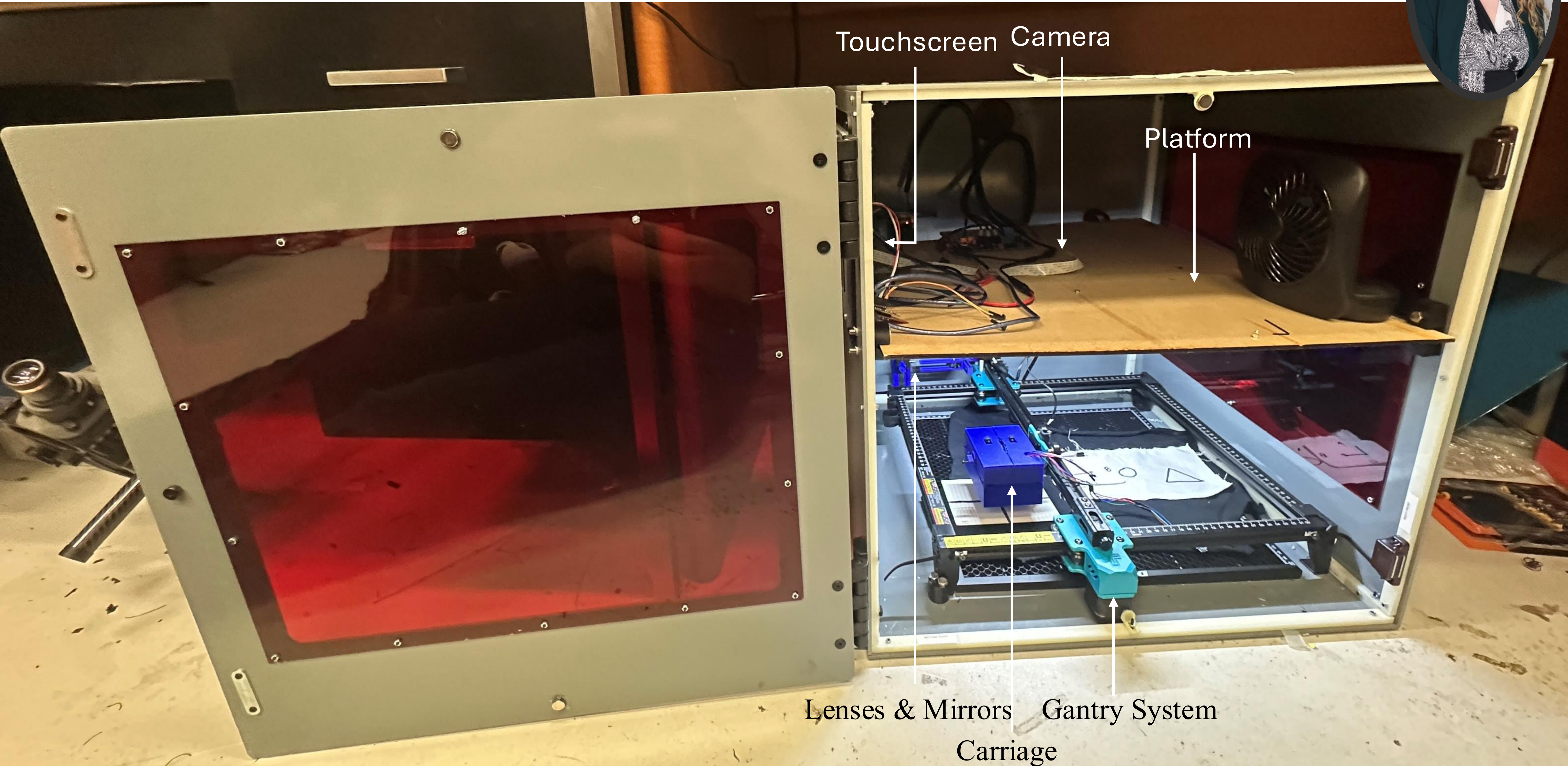
- **Advanced**
  - Wattage incident on mirrors is >.5 watts
    - Display live job preview or camera feed for alignment verification
    - Log system faults automatically to system’s internal storage in a first in first out manner based on available storage
    - Recall default jobs or material presets from internal storage without the need of any markings
    - Implement a buzzer to provide audible feedback for key system notices such as job completion, errors, and emergency stops
- **Stretch**
  - Implement an onboard data logging system that records job metadata (duration, laser power, material type, completion status) and all system errors
    - Log entries include timestamps, job ID, and error code fields
    - System stores a minimum of 50 records in local storage without corruption.
    - Logged data can be exportable as a .txt file

Motivation, Background, and Existing Projects

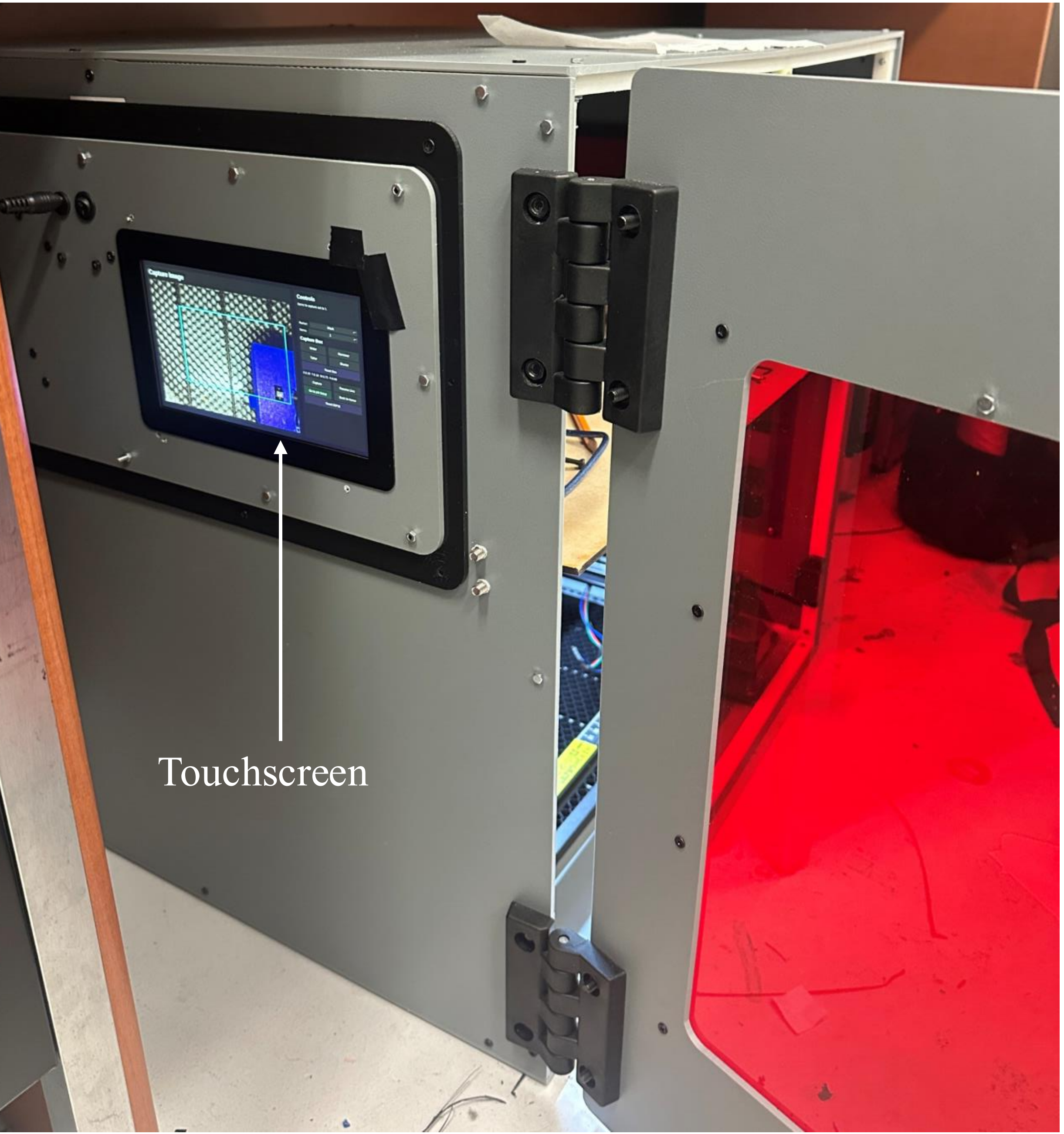
- Make fabric cutting easier
  - No computer software or file upload is needed
  - For those without knowledge of traditional laser cutting software
- Useful for hobbyists, designers, and manufacturers

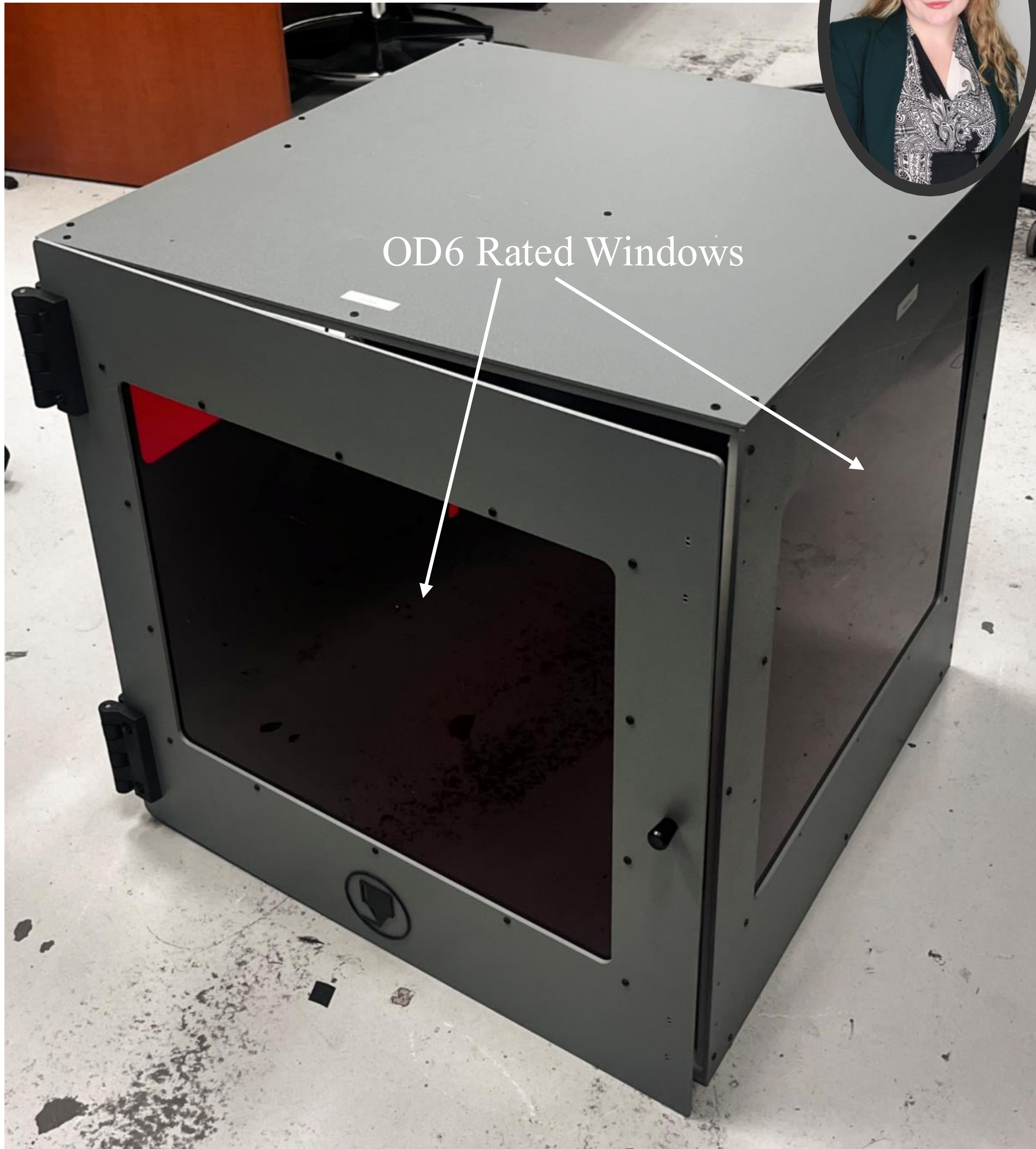
- Commercial Laser Engravers
  - Do not focus on fabric cutting
  - Laser is not stationary and moves using gantry system
  - Wattsan 6090 LT [1]
- Automated Parameter Adjusting Laser Engraving System- Group 5Senior Design F23-S24999 [2]
  - Similar to our system but with the goal of engraving different materials
  - Features a spectrometer system
  - 6-person group

Final Prototype

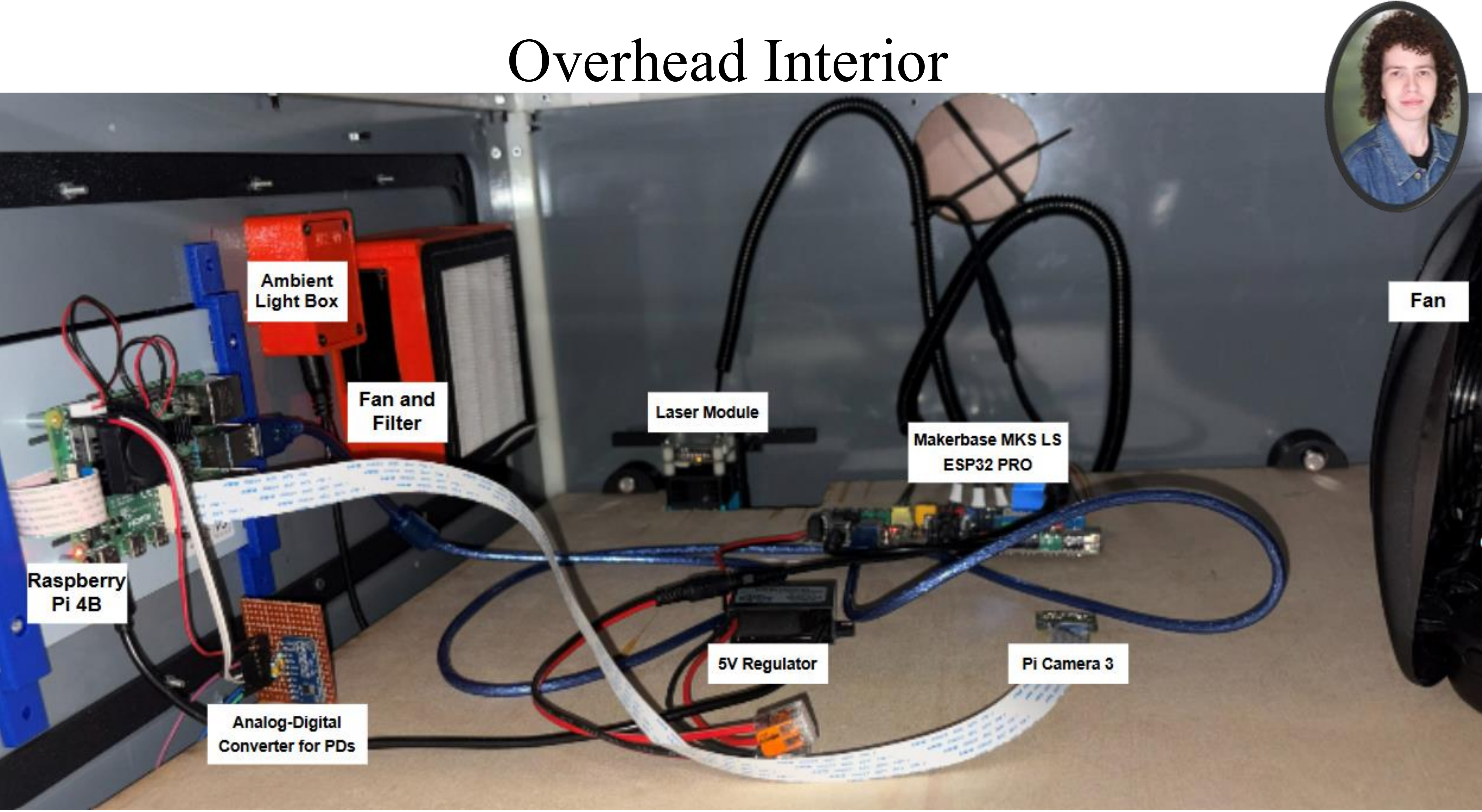


Exterior





Overhead Interior



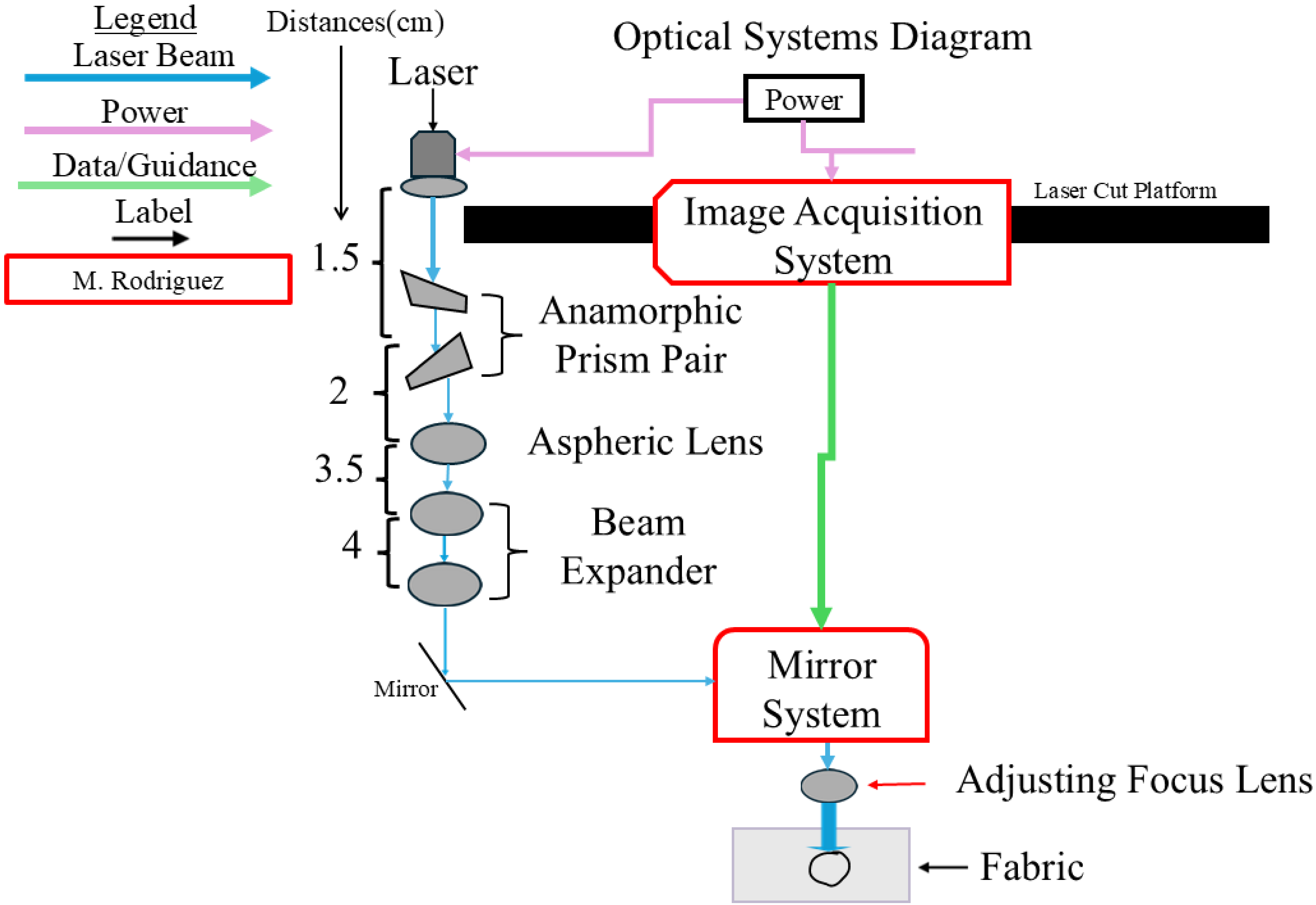
Engineering Specifications

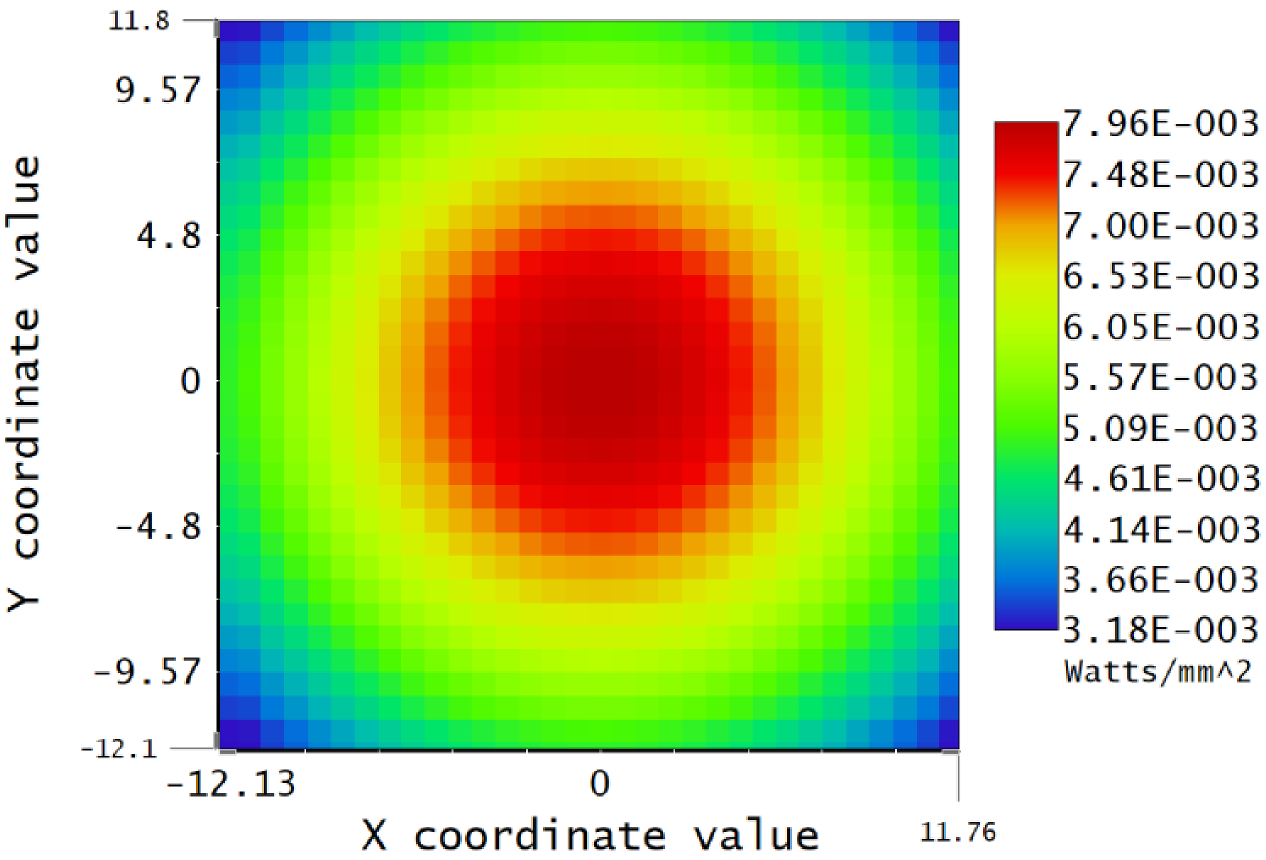
Accuracy of Image Processing Traces	>90%
Laser redirection speed	10-30 Millimeters per minute, depends on fabric type and thickness
Kerf width size on fabric	<100 microns
Screen Resolution	720 x 1280 pixels
HMI Boot Time	≤35 seconds

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





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

Partial Optical Simulation

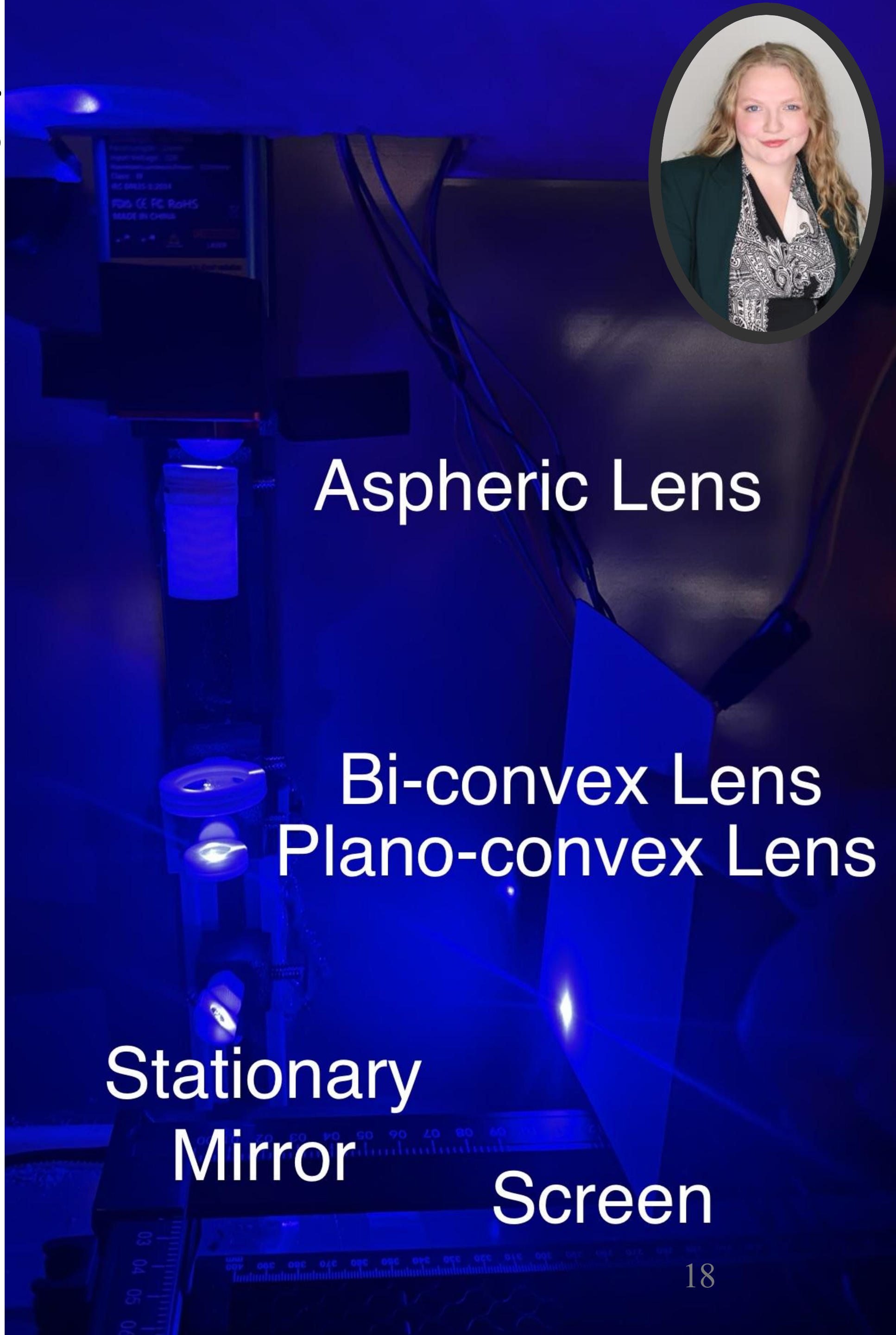
- Helpful to give us an idea of how our power would be impacted by our lenses
- Demonstrates maximum width of 13.2 millimeters
- Maximum wattage of 7.96 milliwatts per mm^2
- Using Irradiance equation below

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

  - Maximum Irradiance = 58µW
- Not completely accurate, uses a point source instead of our laser source

Optical Testing

- Since the laser that comes with our engraver diverges, we chose to minimize the beam instead of expanding a large beam
- Doing this minimizes the stray laser light in the enclosure
- Initial expanded beam is on the left
- Minimized beam is on the right



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

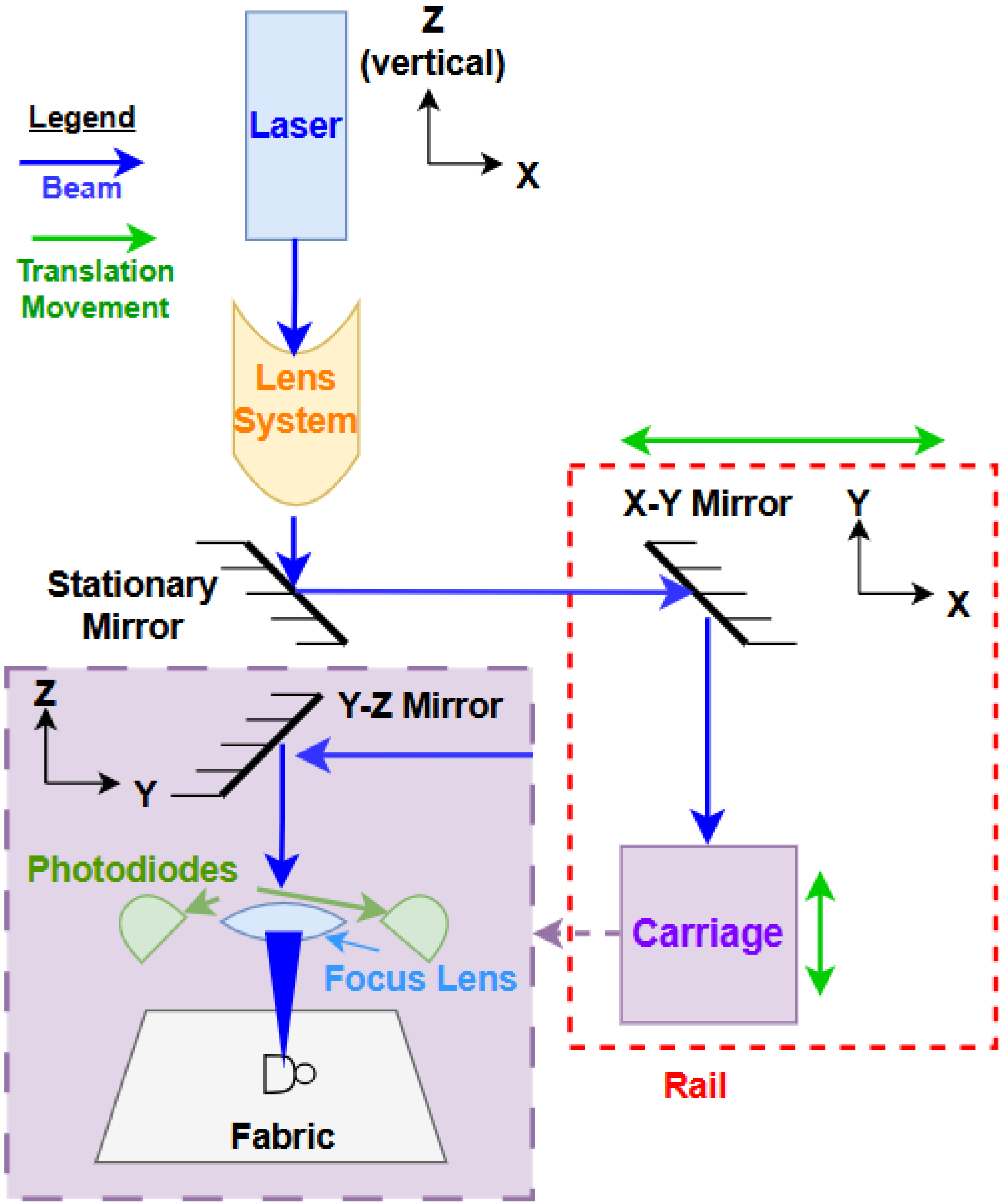
Hardware Comparison: Photodiodes

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

- Opting for simple series resistor instead of TIA design.

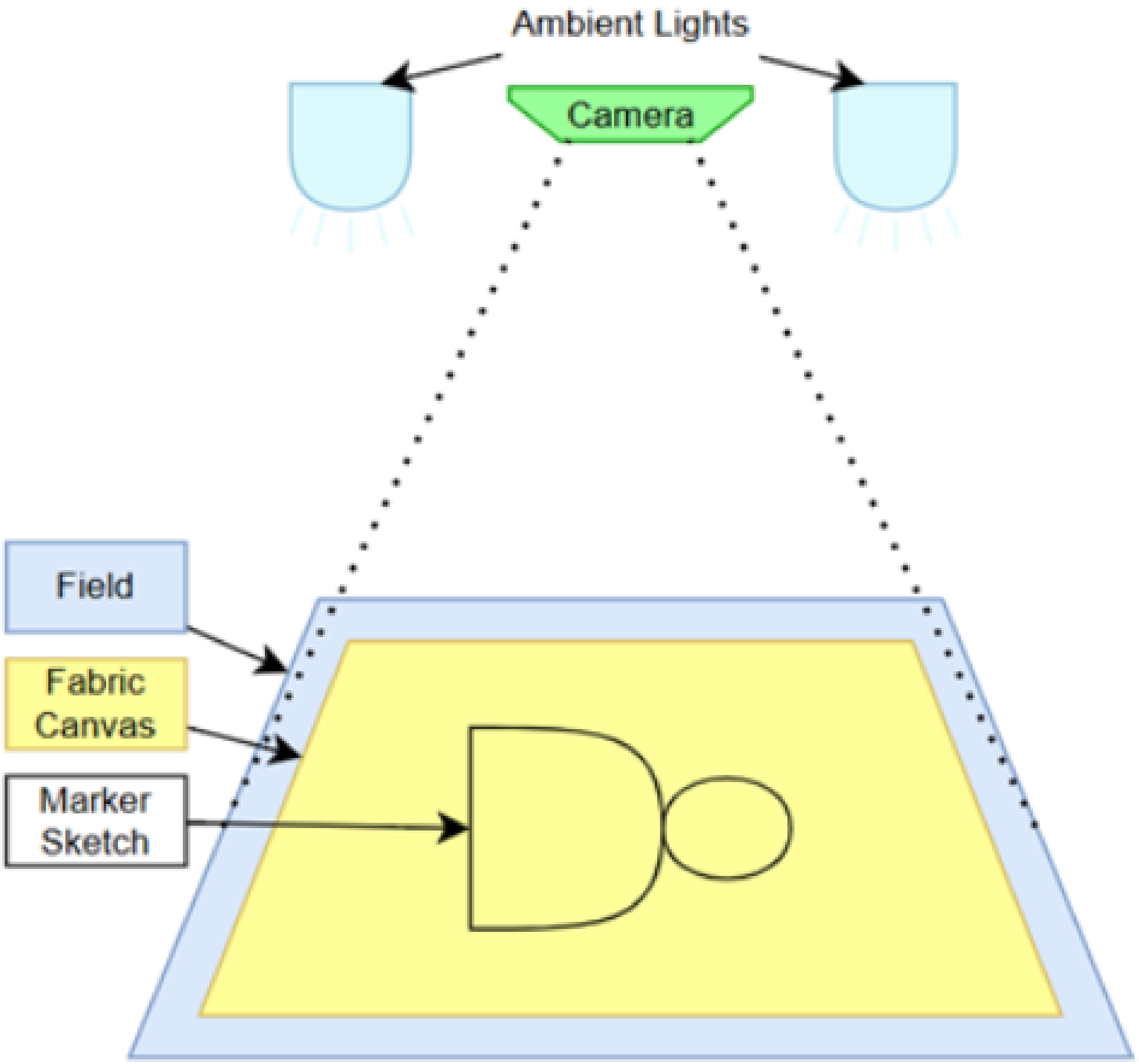
Hardware Comparison: Focus Lens

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

- Three mirrors attached to the gantry direct the beam
- One mirror is stationary; redirecting the beam from the lens system to the mirrors on the gantry
- Two mirrors on the gantry translate independently in X and Y directions
- After the Y-Z mirror, the aspheric lens focuses the beam to a small spot on the fabric, ensuring a thin, clean cut
- Photodiodes are set next to the focus lens detect scattered light

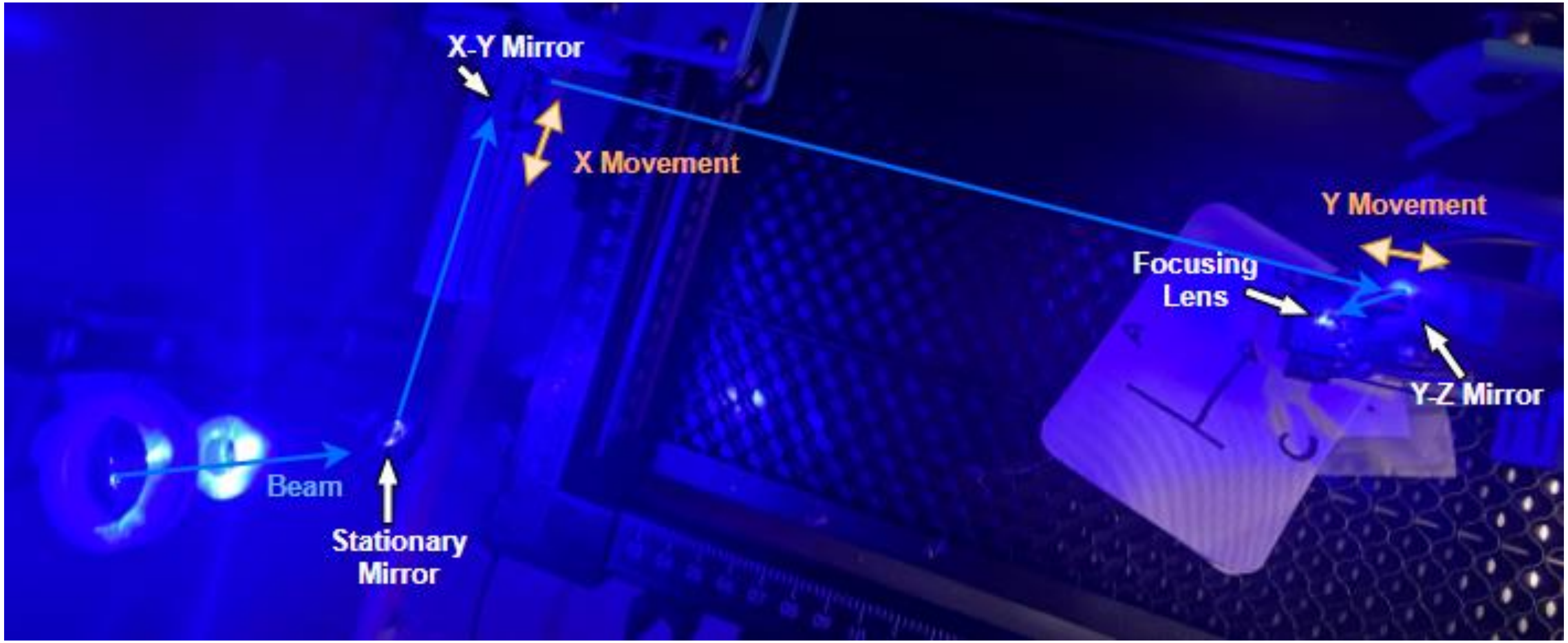


Camera Setup

- Camera is set at a height such that the capture area is within the 300mmx300mm area of the gantry
- Ambient lights over the fabric will make sure the markings are highly visible to the camera
- The gantry will move out of the way and ambient lights on so that the camera can take a clear snapshot of the fabric.
- The snapshot is then sent to the Raspberry Pi for image processing and analysis.

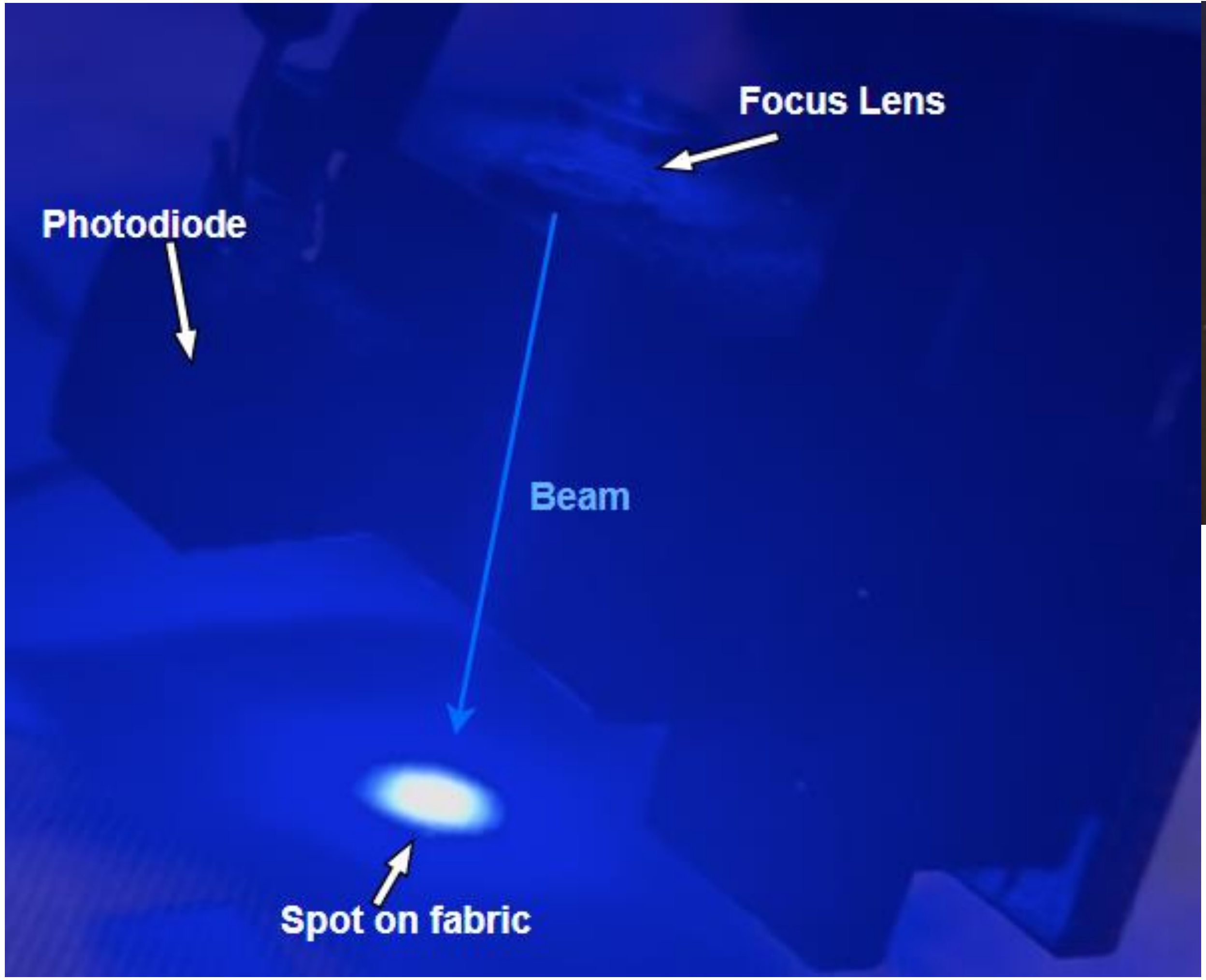
Mirror Guiding System Setup

- Beam is meticulously aligned so that maximum beam intensity is on the fabric at any point on the gantry
- The system is incredibly sensitive to movement and vibrations
- Mirrors and focus lens are adjustable for alignment and changing focal spot height

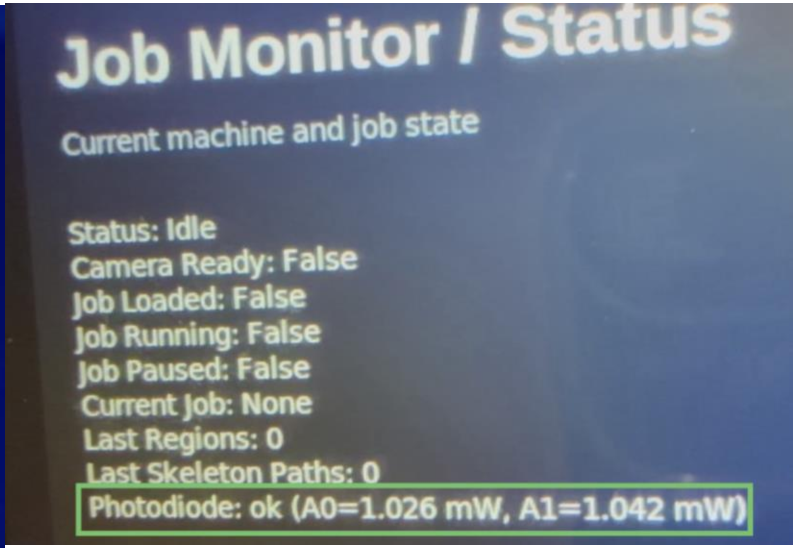


Top-down view of the gantry with the laser on at low power

Photodiode Setup



Downward view of the bottom of the carriage with focus lens and photodiodes(hidden behind plastic). Focused laser spot is on white cotton.



Photodiode readings to the Raspberry Pi displayed on-screen during a cutting job.

- Two blue enhanced photodiodes are mounted on either side of the focusing lens; on the same unit.
- They are angled 7.12° inwards to face the spot, analyzing scattered reflections
- This information is sent to a Raspberry Pi for the user to view during the job

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

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
Photodiode	5V	Variable µA

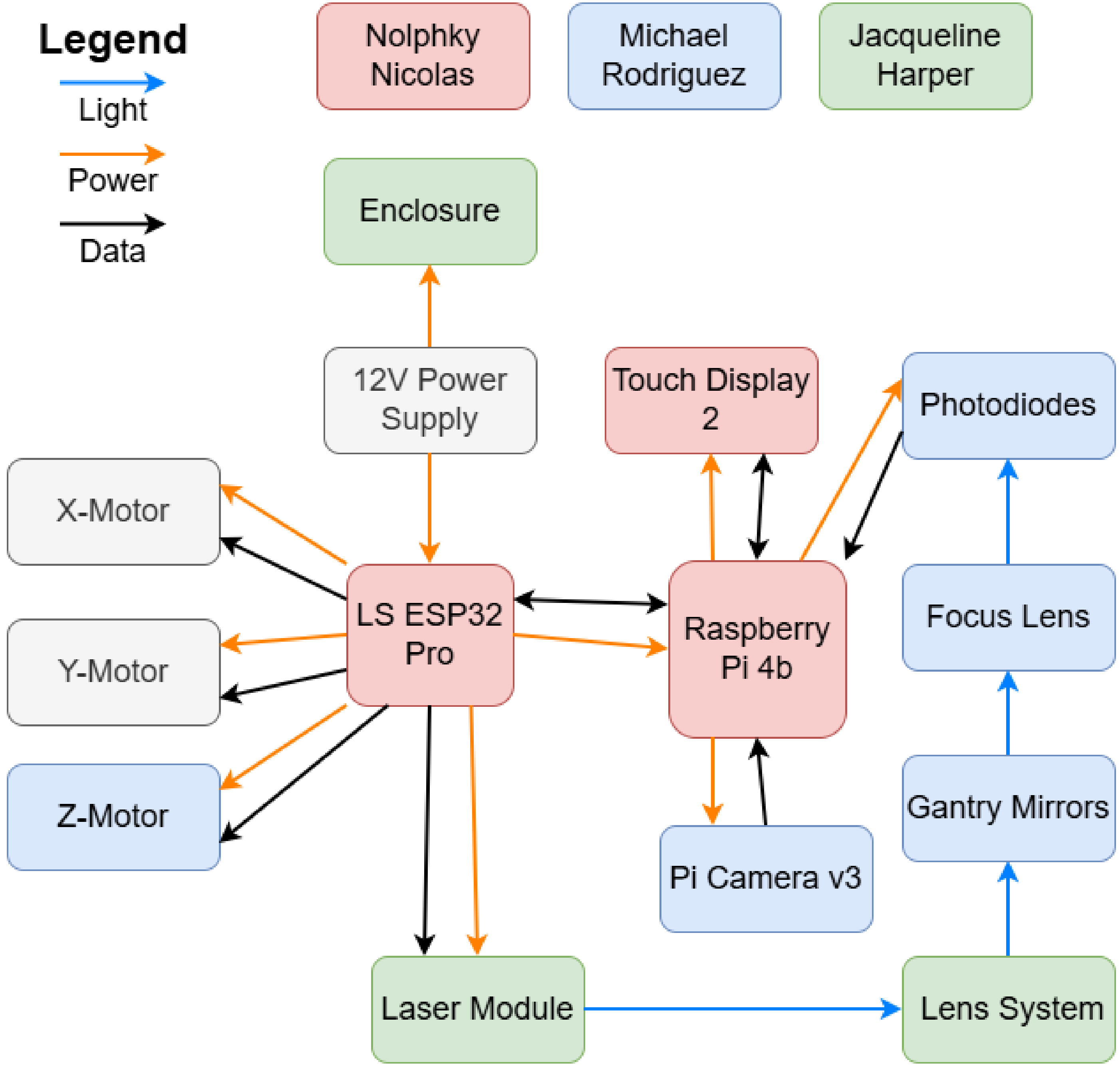
Hardware Comparison: Main Controller

	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

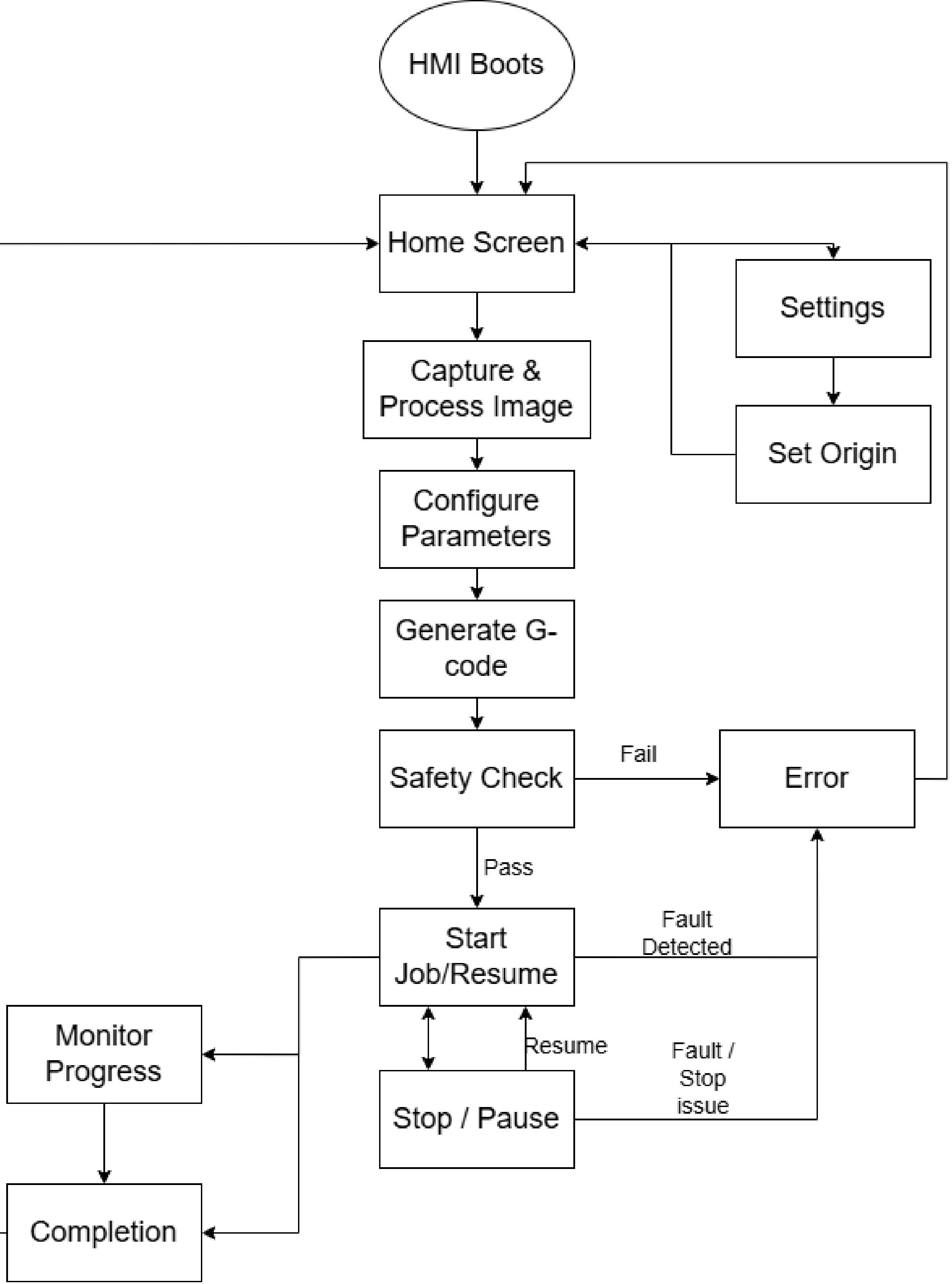
	Raspberry Pi Touch Display 2	Generic 7” HDMI touchscreen	10.1” HDMI Touchscreen
Resolution	720x1080	1024x600	1280x800
Size	7"	7"	10.1"
Touch spec	Capacitive 5-touch	(5-10 touch)	(5-10touch)
Connection to pi	DSI ribbon (video) + 5 V GPIO (power/touch)	HDMI (video) + USB (touch) + 5 V barrel/USB (power)	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

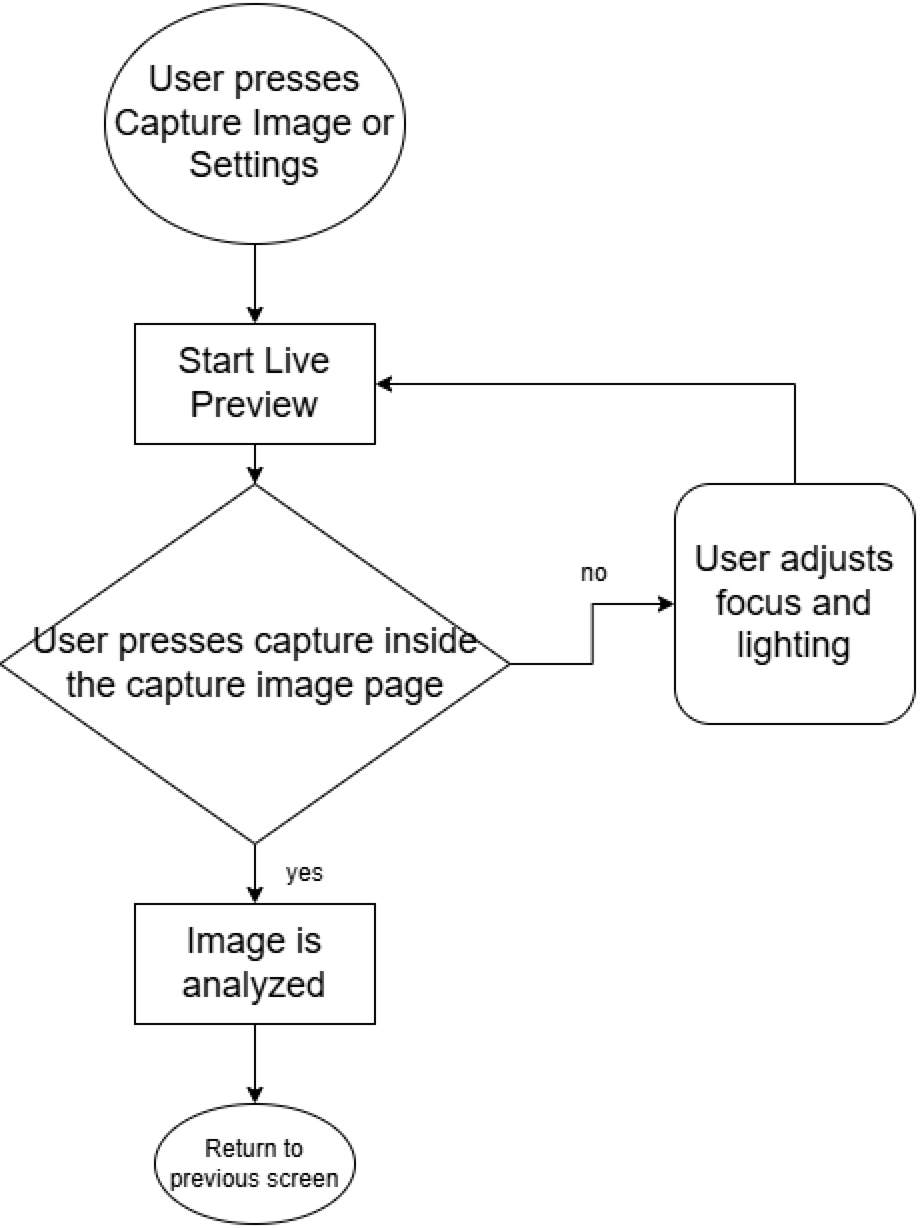
	Python	C/C++
Pros	• Rapid development and fast iteration • Extensive libraries (OpenCV, NumPy, Tkinter, serial) • High readability and maintainability	• Compiled language with deterministic timing • Minimal memory overhead • Suitable for real-time embedded systems
Cons	• Interpreted language leading 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	The firmware of the ESP board (motion control, PWM laser modulation, safety interlocks ect)



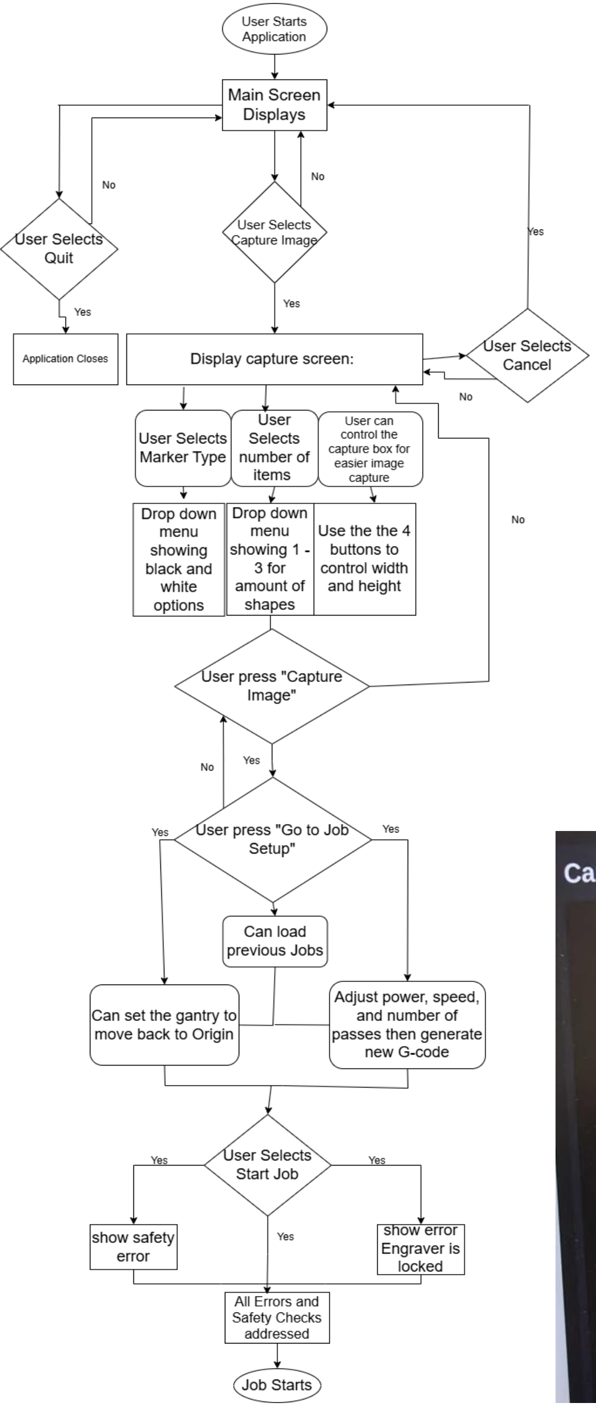
Software Flowchart

The Software is intended to be simple and easily navigable by anyone using the machine. The user should be able to take a picture, modify some parameters and start a job. When a job is currently running, they should be allowed to pause or stop a job if they so choose.

Software Flowchart: Camera

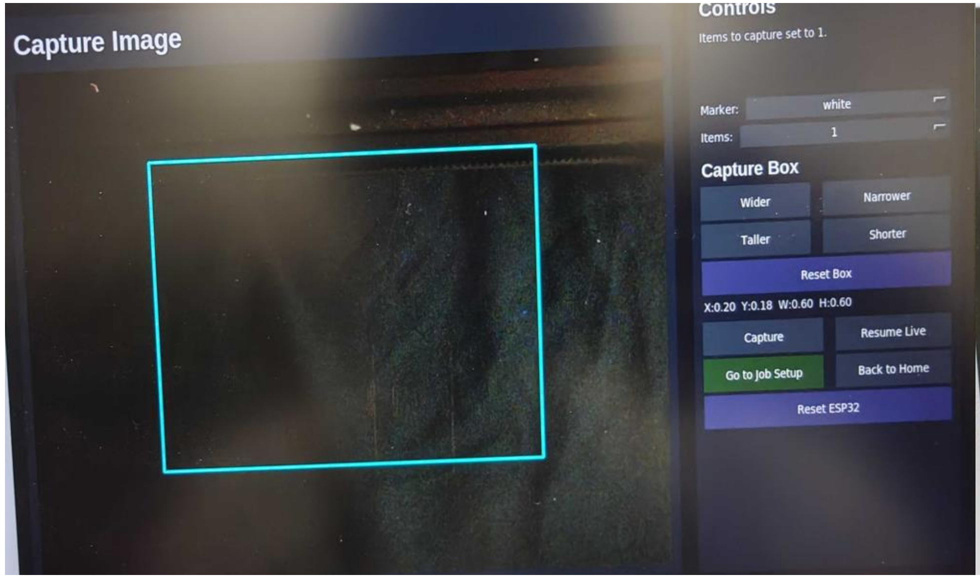


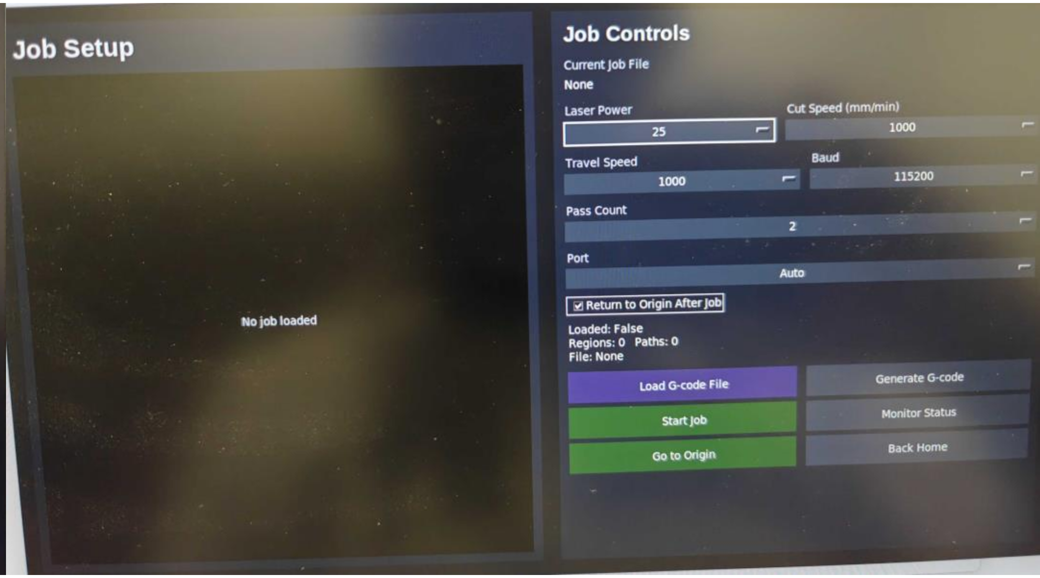
The figure to the left illustrates the automated marker detection section of the touchscreen interface. When the user wants to see what the camera is capturing, the application initiates a live video preview from the onboard camera from the capture image page or the settings page. From the capture image page the system can perform marker detection to identify the alignment trace. If the marker is not detected or appears unclear, the user may adjust focus or lighting conditions to improve visibility before the detection routine repeats. Once the marker is successfully detected, an overlay is aligned to its position, allowing precise registration between the camera feed and the marker trace.

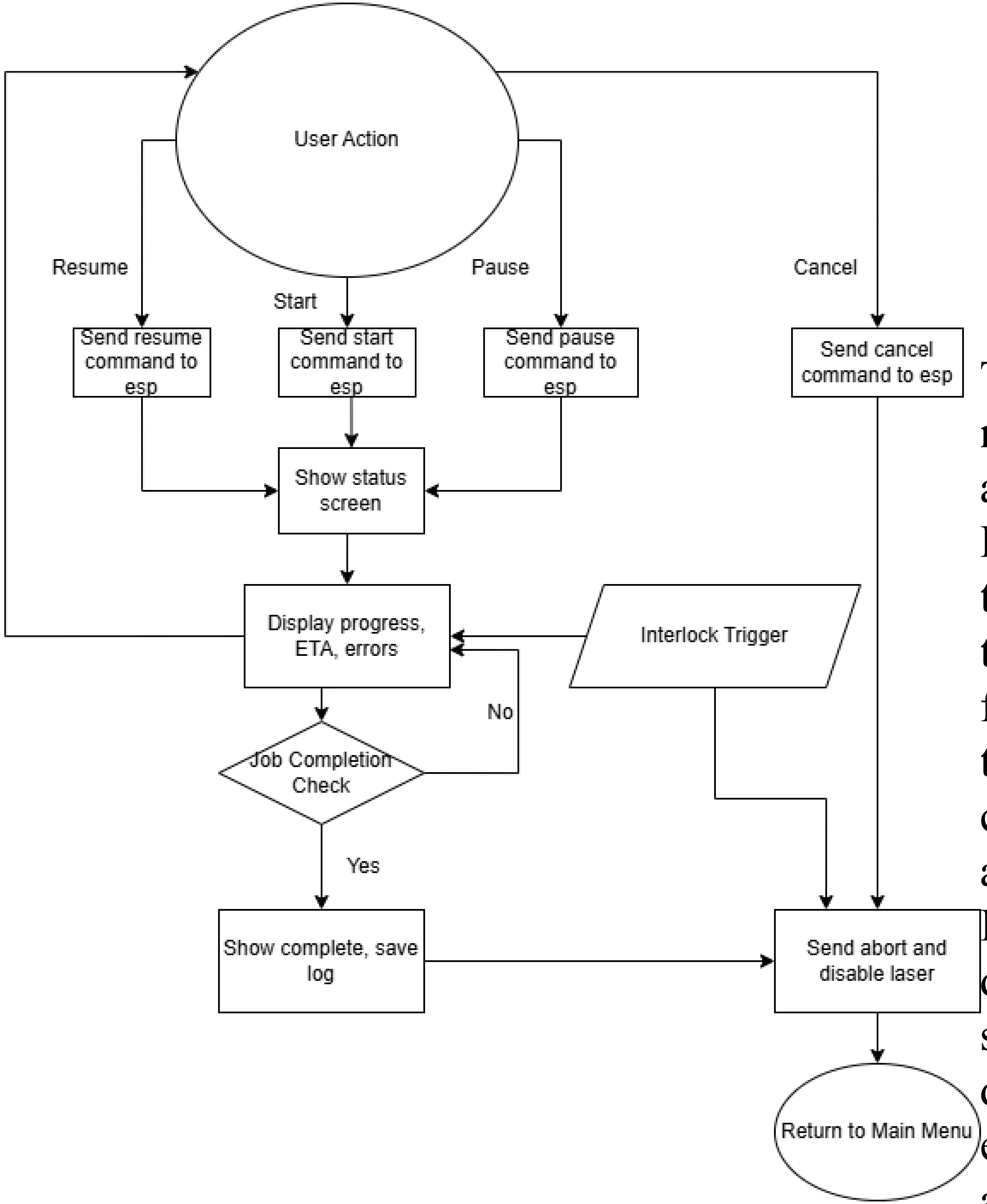


Software Flowchart: Job Start

The image to the left demonstrates the software logic for initiating a laser cutting job through the UI. The user must take a picture of the fabric with the drawn shape under optimal conditions, then move to job setup page where they can tweak some parameters such as the power of the laser and the speed of the gantry. After all of these parameters are set, the user can generate new G-code and start a job. Below are the 3 pages concerning this process.



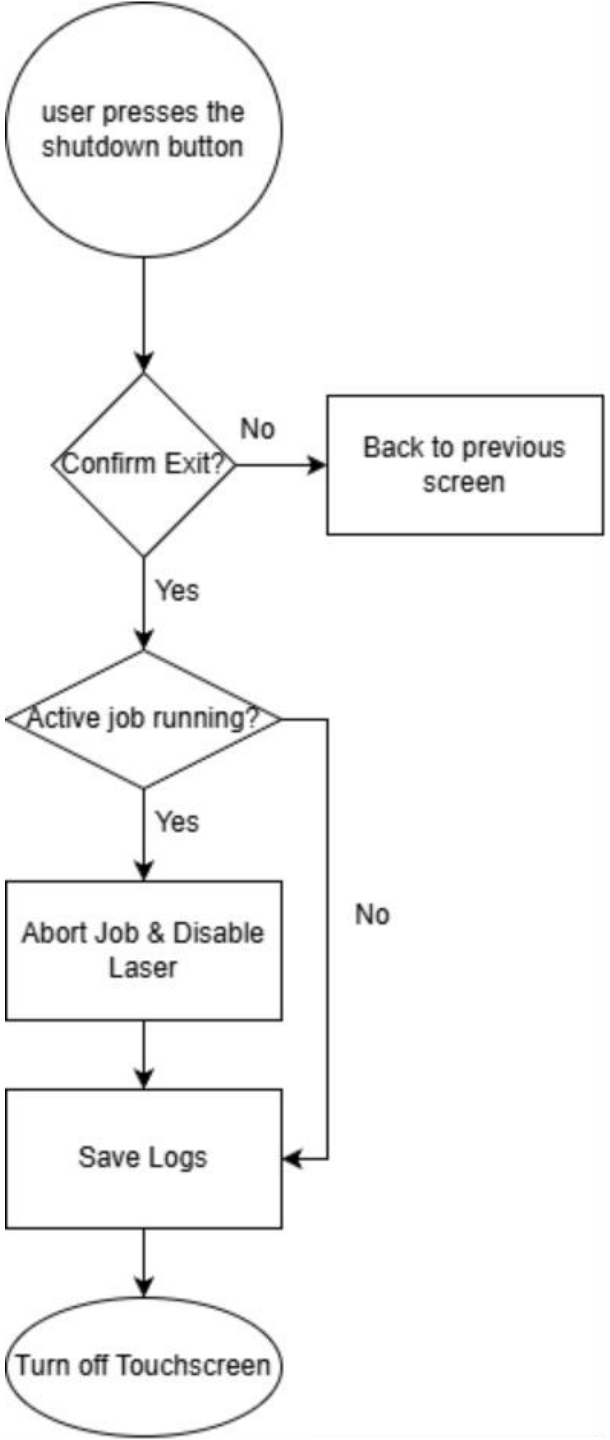




Software Flowchart: Job Monitoring

The figure to the left shows the logic implemented for job monitoring and safety management. When the user performs an action such as **Start, pause, Resume,** or **Cancel,** the Raspberry Pi 4B sends the corresponding command to the ESP32 board, which controls laser gating and motion timing. During active operation, the system displays live feedback including progress, estimated time to completion, temperature, and error information. A continuous completion check ensures that once the job finishes, the system logs results and returns to the main menu.

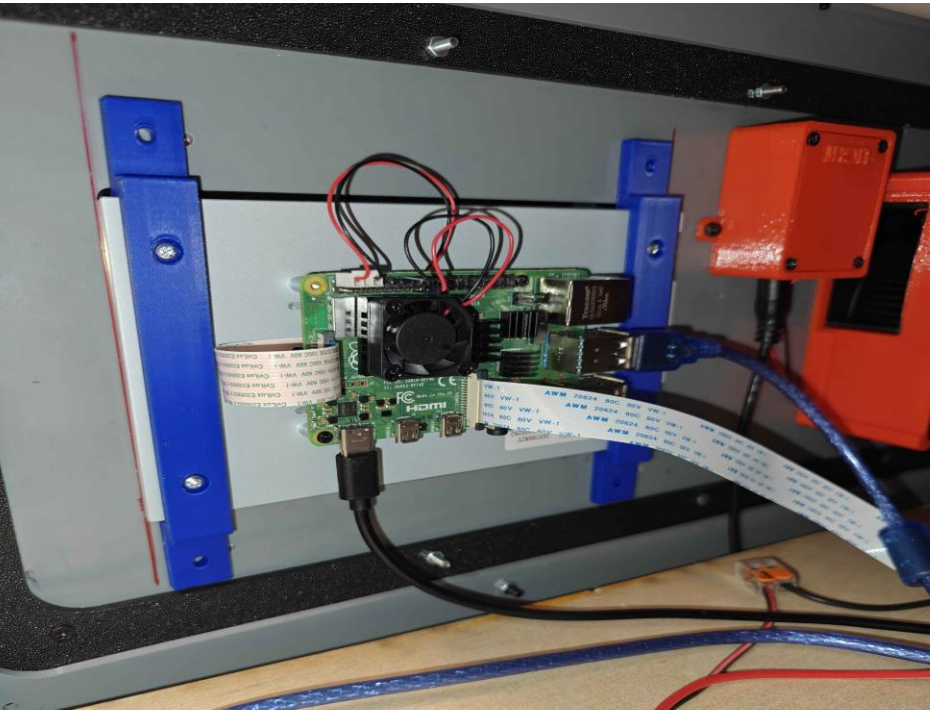
In parallel, the software monitors all safety interlocks. Any detected fault, such as a temperature spike, immediately triggers an **Abort** command to the ESP, disabling the laser and halting all activity. This structure ensures deterministic safety behavior and prevents dangerous accidents during unattended operation.

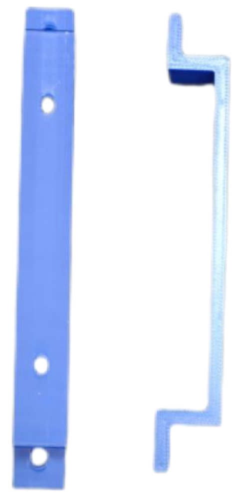


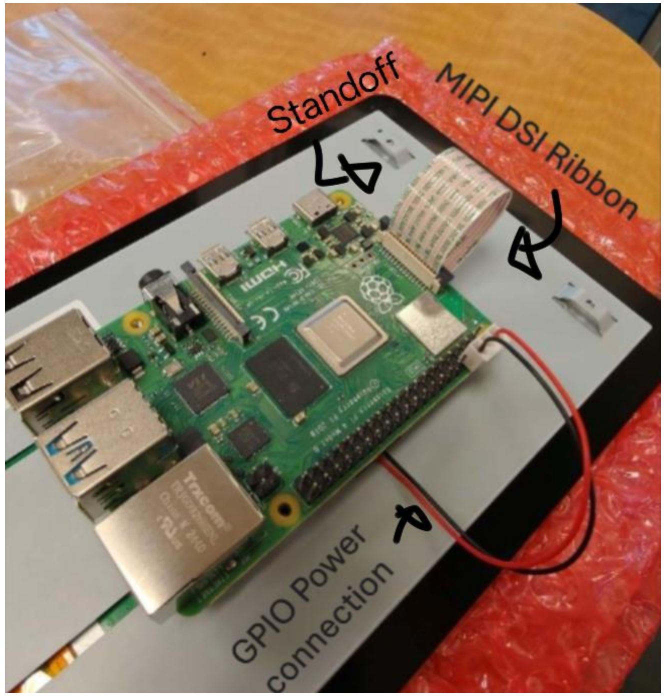
Software Flowchart: Shutdown

The flowchart to the left illustrates the shutdown routine for the touchscreen interface. When the user presses the shutdown button, the system first requests confirmation in order to avoid unintended exits. If confirmed, the software performs a check to see if any cutting job is currently active. If a job is running, an abort command is sent to disable the laser and motors, then save operational logs before completely powering down.

Prototype and Testing: Touchscreen

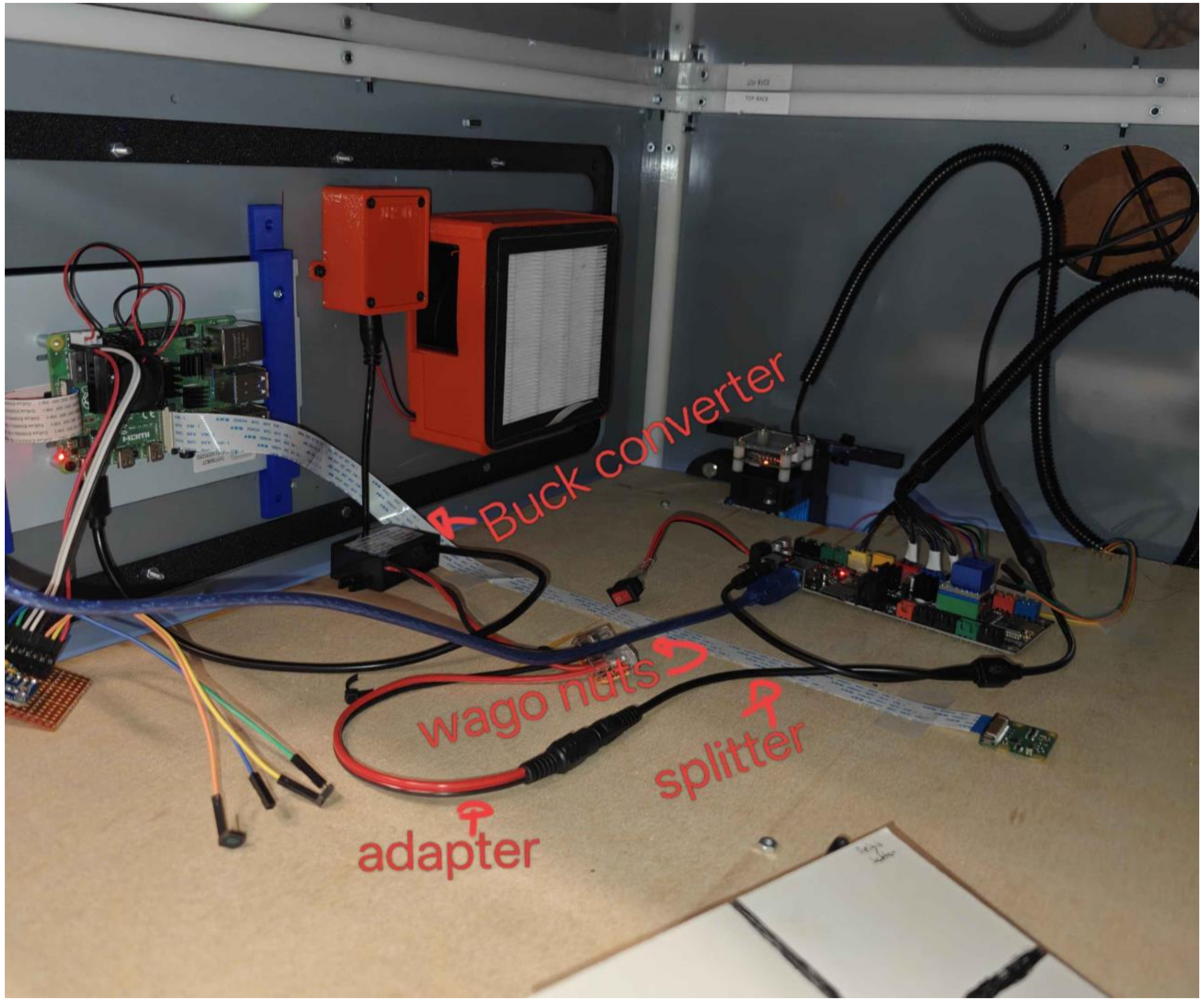






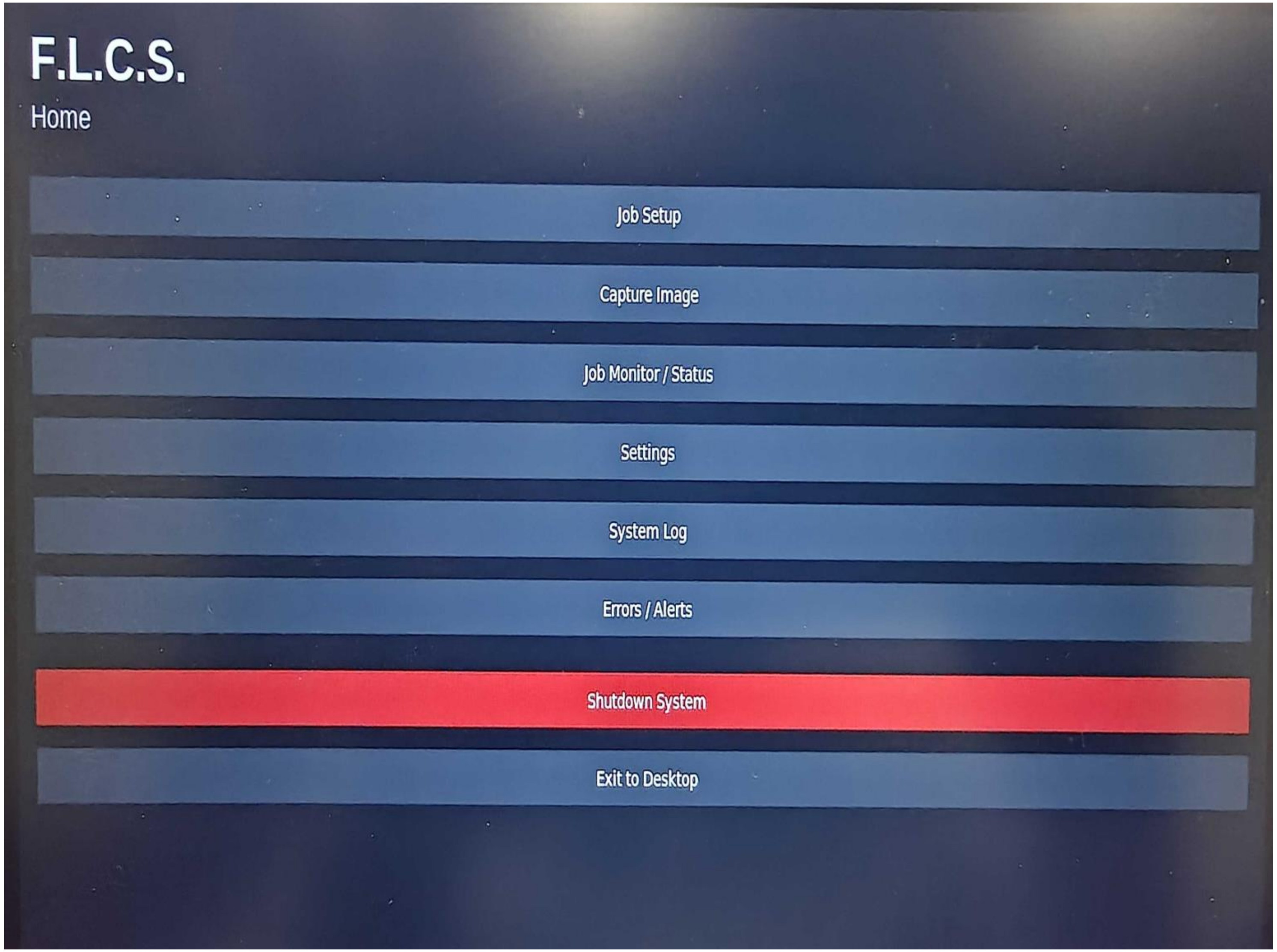
The Raspberry Pi Touch Display 2 was connected to the Raspberry Pi 4B using the MIPI-DSI ribbon cable that came with the latter and powered using the 5 V and GND pins on the Pi's 40-pin header. To secure the touchscreen, create brackets with counterbored 2.5mm holes and secure them over the standoff holes on the back of the touchscreen. That will keep the touchscreen from falling out and the touchscreen will keep them from falling in.

Prototype and Testing: Touchscreen Continued



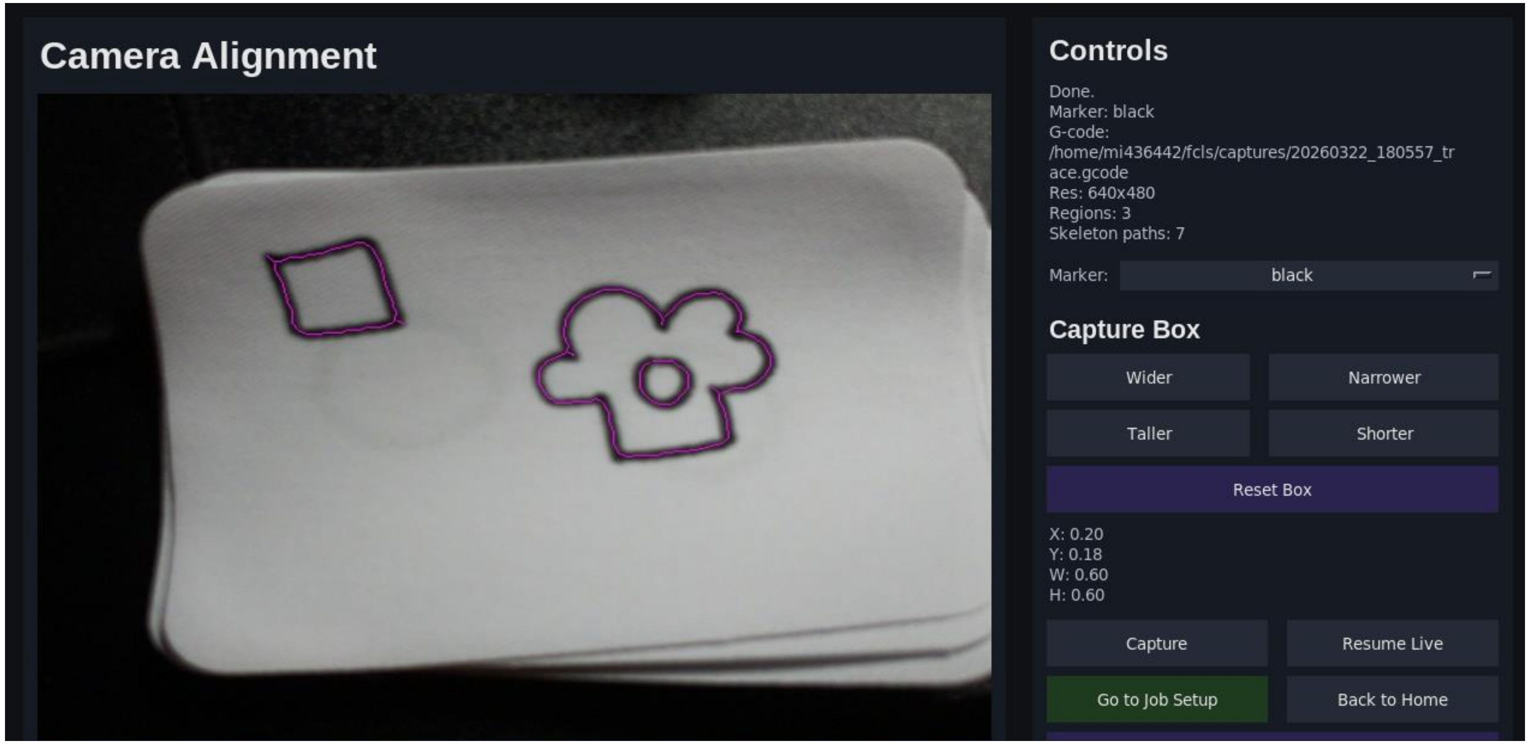
The image to the left demonstrates how the pi is powered. 12 volts is delivered from the engraver's power brick, which is split using a splitter where one end goes to the engraver and the other is connected to a power supply adapter. The adapter is then connected to a step down 12v to 5v buck via a double wired wago nut.

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. The exit to desktop page is strictly for developer use as of this stage. It will be gone in the final HMI

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

- Problems We Experienced and Solutions
  - Path generation was off. The laser would attempt to cut in the wrong place
    - The reason for this is because the camera isn't capturing the whole working area
    - The solution, although not perfect, was to use the region the camera sees as the working area and set the origin at the lower left corner of it.
  - Unreliable lens mounts
    - Lens mounts were continuously improved to help improve alignment methods for the laser
      - This included testing two different rail systems to find the permanent solution
    - Initial lens mount melted during testing
      - The solution was to use heat resistant PLA
- Future Work
  - Better error handling and full integration with photodiodes, fire detector and buzzer
  - Laser module replacement or modification to make an initial collimated beam

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 lens system • 3D Models • Platform and mounts to properly secure components • Housing selection and laser system integration
Michael Rodriguez (PSE)	• Mirror guiding system and carriage • Final lens focusing onto fabric • Camera Height • Photodiodes for scattered beam light detection
Nolphky Nicolas (CPE)	• System Software Integration • HMI interface • Image acquisition and gantry path generation

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/.