Enhanced Laser Inkless Printer

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Chapter 2: Project Description

2.1 Project Background and Motivation

Our senior design project focuses on enhancing the Laser Inkless Printer (LIP), an innovative proof-of-concept device originally developed to eliminate the need for traditional ink and toner cartridges [1]. The prior team's design successfully demonstrated the potential of laser-based printing as a sustainable and cost-effective alternative to conventional printers, addressing the recurring expenses and environmental concerns associated with ink and toner waste. Their prototype demonstrated that a laser can mark paper to create legible text without the use of consumables, thereby opening the door to more eco-friendly and low-maintenance printing solutions. However, their work also revealed critical areas for improvement, particularly in terms of speed, reliability, and system integration, which our team will address to advance the feasibility of this technology further.

One of the most pressing issues identified in the previous design was the slow print speed, which made the device impractical compared to modern printers. Our team is dedicated to tackling this challenge by optimizing both the laser operation and the motion control system to achieve faster throughput while maintaining legibility. Additionally, the earlier project faced power management difficulties that affected stability, as well as challenges with PCB design that necessitated a costly restart late in development. We aim to refine these elements by carefully redesigning the control circuitry, improving thermal regulation, and ensuring efficient integration of all components. Another constraint was affordability, both for the prototype and for eventual consumers, as high costs in parts limited scalability. Our team will focus on cost-conscious component selection and system optimization to strike a balance between performance and accessibility.

By addressing these limitations –speed, power management, affordability, and system reliability – we are motivated to build upon the foundation laid by the previous team and move the LIP concept closer to a practical, consumer-ready device. Our enhancements shall not only improve the overall user experience but also strengthen the environmental and economic benefits of an

inkless printer. With each refinement, the project advances the possibility of providing households and businesses with a sustainable, cost-efficient, and low-maintenance alternative to traditional printing.

2.2 Component Sources and Real-World Context

In our design, every component selected—ranging from the ATSAM3X8EA master microcontroller, STM32F303R8 motor-control MCU, HC-05 Bluetooth and HD44780 LCD modules, to the stepper motors, laser diode, and drivers—was informed by the previous team's documented work. Their final report detailed the rationale and sourcing for each part, such as the STM32's availability and cost and its superior PWM/timer capabilities, as well as the HC-05 and HD44780's affordability and compatibility with microcontroller voltage domains. We have been verifying suppliers for these parts (e.g., electronics distributors, surplus stores, university labs) and cross-checking functionality within our enhanced system architecture to optimize cost efficiency within the project design.

To place our work in a broader context, it's worth noting that laser-based printing technology is far from theoretical—HP's long-running **LaserJet** series exemplifies commercial inkless printing, using laser beams and toner rather than liquid ink to create durable prints. Although these printers still require toner, they illustrate the advantages of laser imaging: high resolution, fast speed, and smudge-resistant output. In a different vein, **ZINK** (Zero Ink) technology offers truly inkless, full-color printing using heat-sensitive layers within specialized paper—no liquid ink or toner required—and has been adopted in compact photo printers by companies like HP, Lifeprint, and Polaroid.

2.3 Descriptions of Features

The Laser Inkless Printer (LIP) integrates a number of features specifically chosen to optimize performance, safety, and scalability. The stepper motors are a core feature, selected over DC motors because they provide discrete precise positioning without the need for complex feedback systems, making them ideal for high-resolution printing. The motor drivers enhance this by supporting microstepping, which allows finer motion control and reduces vibration. Limit

switches serve as another feature, included to establish consistent home positions and protect the gantry from damage due to overtravel. On the laser side, an optically isolated switch (G4 ODC5) was chosen as a feature to ensure safe separation between high-power circuits and the low-voltage logic of the microcontrollers.

The power management system, with regulated voltage and thermal control through a fan and heat sink, ensures that the diode operates safely and reliably. At the system level, a distributed microcontroller architecture was adopted as a feature – the ATSAM3X8EA functions as the master for coordination, while the STM32F303R8 handles motor control, and the ATmega328PB manages low-overhead peripherals like the LCD. The modular design feature reduces latency and makes troubleshooting more manageable compared to a single-controller system.

The updated laser system is planned to utilize a 520 nm green laser diode set within an optical cavity similar to the old design. The previous group considered a green laser, as green lasers have been documented as powerful engravers for metal, plastic, or wood [3]. However, it was disregarded as there wasn't enough formal documentation of its engraving capabilities with paper. In addition to advancing the previous design, our project will provide valuable insights into the effectiveness of a green laser in etching paper. The lens system is planned to employ smaller lenses with similar coatings and focal lengths to those of the previous project. Simulations on Zemax shall be performed to determine the appropriate lens diameter and distance when creating the smaller optical cavity. There has been difficulty in obtaining lens data for plastic lenses; therefore, glass lenses of similar specifications will be used for the simulations.

2.4 Functionalities

The following features collectively provide the LIP with key functionalities that support its operation as an inkless printer. The stepper motor and gantry assembly enable precise x-y positioning of the laser, ensuring accurate marking of text and images on the paper. The inclusion of limit switches enables homing, which is crucial for repeatability and reliable restarts after interruptions. The laser subsystem, enhanced by isolated switching and thermal management, provides safe and consistent energy delivery to print surfaces while preventing hardware damage.

Power regulation enables stable operation across components, preventing failures that plagued earlier prototypes.

On the computational side, the master-slave microcontroller arrangement provides efficient task distribution: the ATSAM3X8EA handles high-level coordination and communication, the STM32F303R8 executes precise motor and PWM control, and the ATmega328PB operates the display interface with minimal overhead. This structure ensures smooth parallel operation and reduces system bottlenecks. Collectively, the functionalities achieved allow the LIP to operate as a reliable, efficient, and safe proof-of-concept device that addresses the affordability, speed, and integration challenges of the prior design.

2.5 Goals & Objectives

Goals

Basic Goals:

- Develop a compact, enclosed printing system that safely directs a low-power laser onto standard paper without ink or toner.
- Implement precise XY stepper motor control for accurate laser scanning across the page.
- Achieve a minimum printing resolution (e.g., 300 dpi equivalent) to validate proof-of-concept printing.
- Ensure user-friendly operation with a basic LCD interface for status updates and control inputs.
- Expand character set support (letters, numbers, symbols) with software-controlled formatting.
- Higher pixel resolution for the numbers, symbols, and characters.

Advanced Goals:

- Optimize scanning speed and synchronization between the laser and stepper motors to improve overall print speed.
- Integrate Bluetooth or USB connectivity for wireless/remote print commands.

- Reduce system footprint by refining PCB design to combine motor drivers, laser driver, and microcontroller on a single board.
- Incorporate safety error detection (e.g., motor stall detection, over-temperature laser shutoff).
- The adjustment for font size (so it can be dynamically changed).

Stretch Goals:

- Implement grayscale or multi-depth engraving capability by modulating laser intensity.
- Enable higher-resolution printing (e.g., >600 dpi equivalent) for more detailed text or graphics.

Objectives

Basic Objectives:

- Implement laser actuation that engraves visible marks on standard office paper without the need for ink or toner, and without causing excessive damage to the paper.
- All electronic components (microcontroller, motor drivers, power regulation, and laser circuitry) will be housed in a single compact enclosure with minimal user calibration required.
- Develop and implement basic laser scanning algorithms on the microcontroller to achieve controlled horizontal and vertical movement of the print head across paper.

Advanced Objectives:

- Reduce power consumption by implementing dynamic power scaling for idle subsystems (motors off during laser-only operations, LCD dimming).
- Maintain system power usage under a set threshold (e.g., <25 W during full operation) to ensure compatibility with standard USB or wall adapters.
- Store print logs and diagnostics in non-volatile memory, allowing persistent data across power cycles.
- Ensure communication protocols (SPI, UART, or I^2C) between MCU and peripheral devices remain reliable with checksum or ACK/NACK error-checking.

Stretch Objectives:

- Achieve near real-time performance (<50 ms delay) between job submission and print initiation.
- Investigate machine learning techniques to adaptively optimize print speed and path planning for different document layouts.
- Enable grayscale printing capability through pulse-width modulation (PWM) of the laser to vary burn depth or darkness.

2.6 Required Specifications

Table 1: Component Specifications

Component	Parameter	Specification	Unit
Green Laser Diode	• Diameter = 5.6 mm • λ = 520 nm • Power = 80 mW	Laser source for etching	1
N-BK7 Photoconvex Lens	• Diameter = 18.0 mm • Focal length = 25 mm • AR Coating: 350-700 nm	Focusing Lens	1
Plastic Aspheric Lens	• Diameter = 5.20 mm • Focal length = 9.85 mm • AR Coating: 400 - 700 nm	Collimating Lens	1
X & Y axis motors	• Bipolar Stepper Motors • 0.5 N*m torque	Control X-Y positioning of laser	2
Paper Delivery Motors	• Geared DC motor with encoder • 0.4 N*m torque	Drive paper feed	1

PCB	• Custom PCB with motor drivers, laser driver, I/O connectors • ~6" × 8"	System control and integration	1
Onboard computer	• Rasberry PI • 1.4 GHz CPU • Microsd or USB compatibility	Control logic, data handling	1
Power Supply	• ≤ 15V Consumption • Able to use power from outlet, 120V 15 A	Supply power to system	1

Table 2: Engineering Requirements

Engineering Requirements	Requirement Specification	Unit
The system will process inputs from an external source within a specified time frame.	≤ 1	s
The paper will be delivered to the correct location within a specified time.	≤ 10	s
The X and Y axis motors will move the laser to the correct location within a certain margin of error.	≤ 5	mm
The system will maintain safe operating temperature during printing to ensure safety for users.	≤ 150	°F
The system will complete a full-page print within a specified time frame	≤ 120	s
The system will achieve a minimum print resolution to make each letter readable.	≥ 30	DPI
The system will not exceed a weight that would make it not portable.	≤ 25	lbs
The system will be able to be fixed on a standard desk.	30” x 60”	in

Figure 1: Hardware Diagram

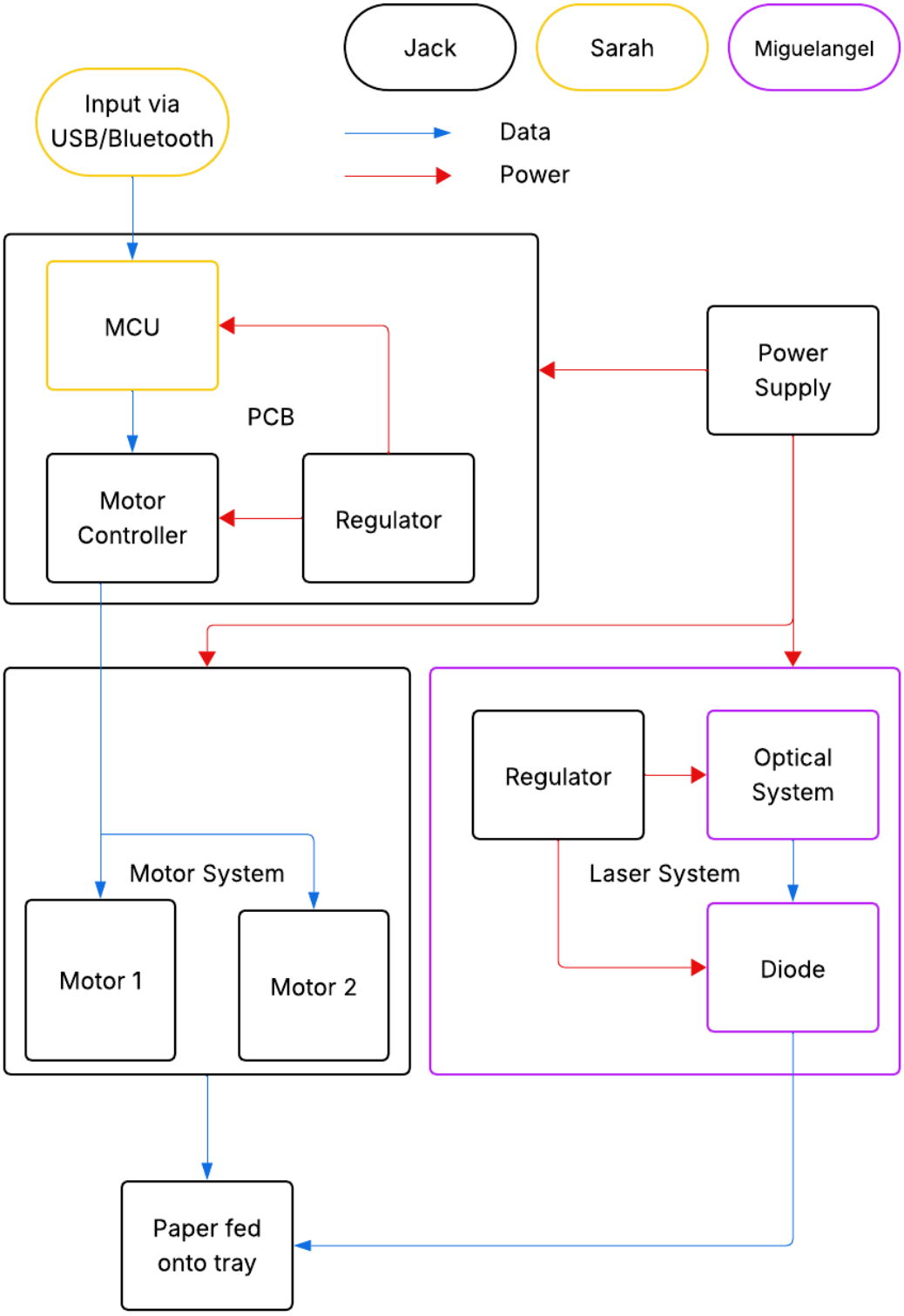
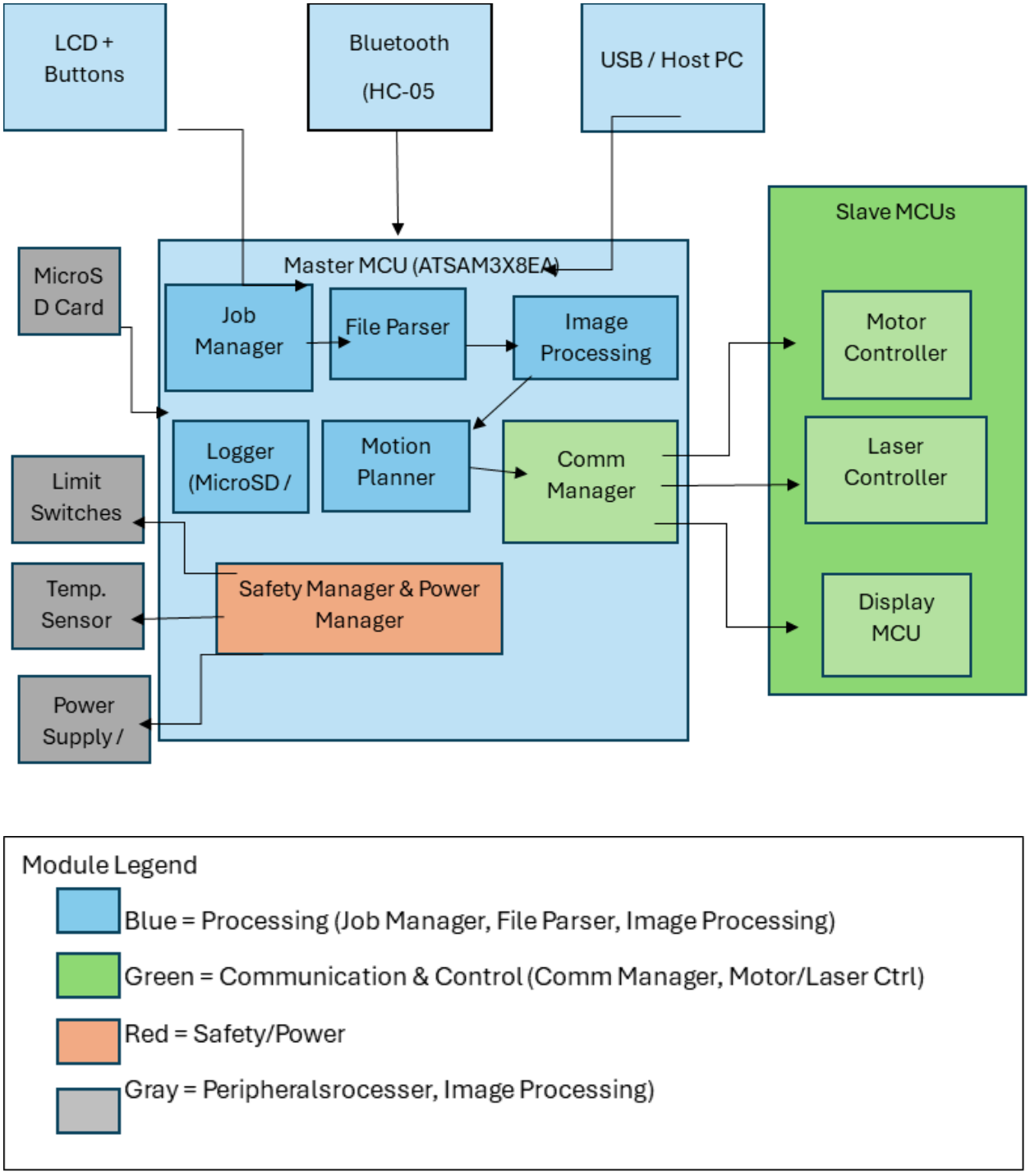


Figure 2: Software Block Diagram



The software block diagram illustrates how the Laser Inkless Printer manages data flow from the user to the hardware subsystems. Input begins through the user interfaces (Bluetooth, LCD, or USB), where print jobs are sent to the Master MCU. Within the Master MCU, the Job Manager and File Parser interpret incoming print data. At the same time, the Image Processing and Motion Planning modules convert it into rasterized commands for precise laser positioning. The communication Manager then distributes these instructions to dedicated Slave MCUs, which control the stepper motors for X-Y movement, the laser module for marking, and the display for system feedback. Supporting managers, such as those in Safety and Interlocks, Power and Thermal Management, and the Logger, ensures safe operation, proper energy use, and diagnostic tracking. Finally, peripherals like sensors, limit switches, and the power supply provide real-time inputs that feed back into the safety and control loops, ensuring the system remains stable, efficient, and user-friendly.

Figure 3: House of Quality

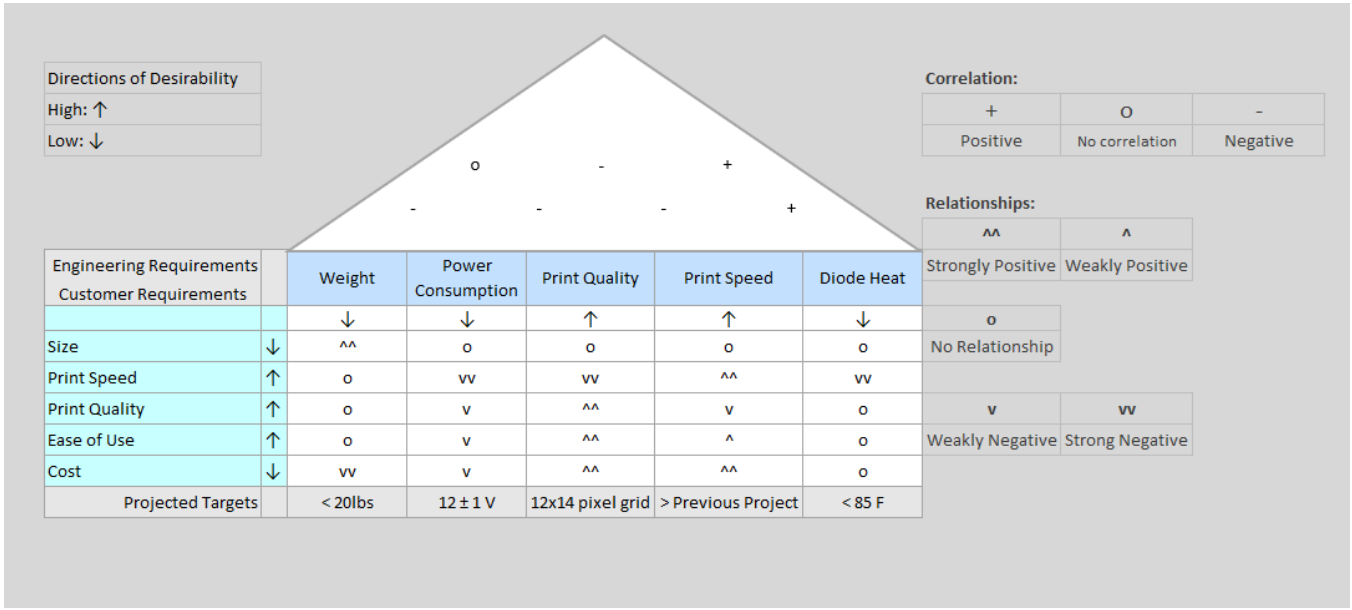


Figure 4: Prototype 3d Model

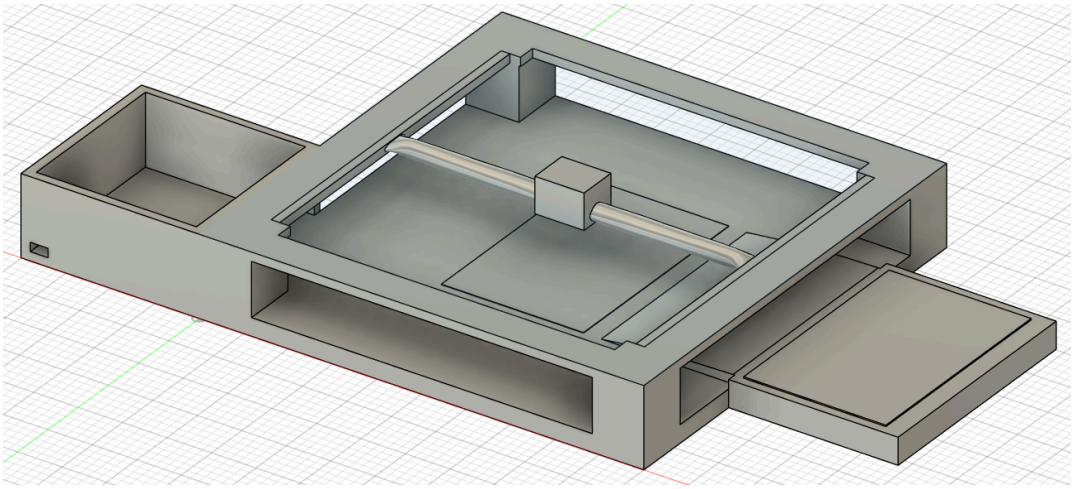
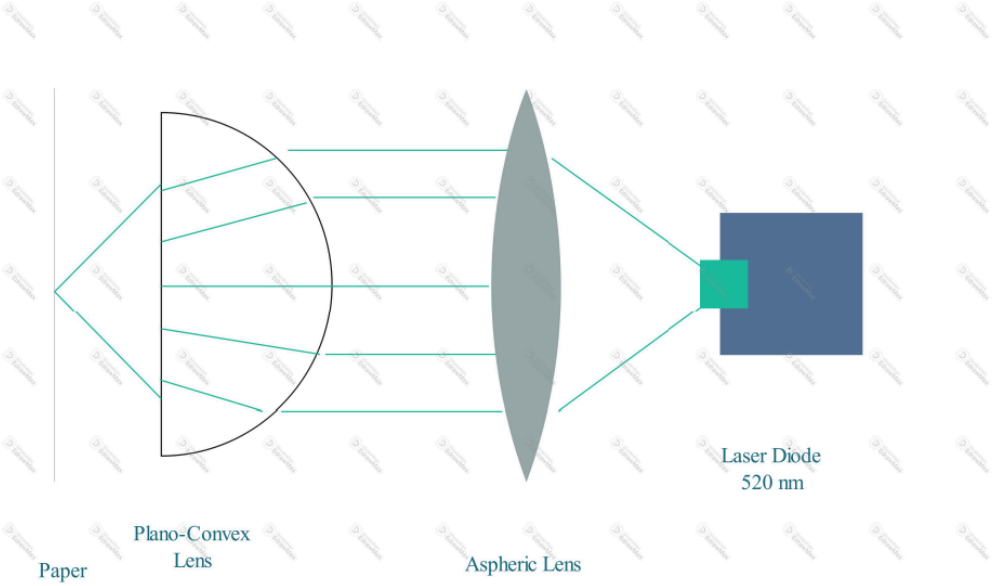


Figure 5: Optical Design Sketch



Our optical design sketch is based on the original design from the previous group. We believe this general layout is ideal for our redesign of the project; however, adjustments are being made to the overall size of the setup, specifically reducing the lenses and distance between components. An enhanced blueprint with added measurements will be included as components arrive and prototyping begins.

Chapter 10: Administrative Content

Budget

Accounting for today's price changes, the previous group spent around $815 on their final project. Utilizing their documentation to guide our process, we agreed on a target budget of $650 to cover our goal of reducing their project cost.

Table 3: Bill of Materials

Component	Part Number/Number	Quantity	Unit Price
Green Laser Diode	Sharp GH05280E2K φ5.6mm Green 520nm 80mW Laser Diode	1	$25.00
Laser Diode Driver	LDS9 (TL)	1	$107.10
Safety Goggles	EaglePairOD7+ 190nm - 540nm	1	$54.00
Plastic Aspheric Collimating Lens	CAW100-A (TL)	1	$25.93
Plano-Convex Focussing Lens	LA1024-A (TL)	1	$87.88
Laser Diode Heatsink	Adjustable Focus Heavy Duty Heatsink / Laser Diode Housing for 5.6mm Diodes with Fan	1	$31.30
Laser Diode Socket	S038S (TL)	1	$5.35
PCB	JLCPCB	1	~$50.00
Raspberry PI	SC0563	1	$26.78
Power Supply	GST25A12-P1J	1	$13.70
Aluminum Rails	B08Y8KL79L	1	$14.99

X & Y axis Motors	17HS16-2004S	3	$12.99
Bolts/Nuts	6259	4	$4.50
Paper Feed motor	NFP-JGA25-370-EN	1	$15.00
Paper	B007JJDTFI	1	$14.96
Total			$435.48

Senior Design Milestones

This project is the final requirement for aspiring engineers at the University of Central Florida. Years of study and examination culminate in the final demo presentation with faculty and reviewers. To ensure our success as a group, planning for consistent milestone achievements throughout Senior Design is crucial. Below is our plan of milestones to achieve during Senior Design 1.

Table 4: Senior Design 1 Milestones

Milestone Number	Milestone Description	Start Date	Anticipated End Date
1	Group Forming & Project Idea	8/26/2025	8/27/2025
2	Project Selection	8/26/2025	8/28/2025
Project Report			
3	D & C Version 1	9/2/2025	9/5/2025 12:00 pm
4	D & C Meeting	9/8/2025 2:30 pm	9/8/2025 3:00 pm
5	Bootcamp Session	9/9/2025 5:30 pm	9/9/2025 7:30 pm
6	D & C Version 2	9/10/2025	9/12/2025 12:00 pm
7	30-Page Draft	9/10/2025	9/17/2025

8	Parts Ordering	9/10/2025	Supplier Dependent
9	30-Page Draft Revision	9/17/2025	9/20/2025
10	Optics Midterm Demo	10/7/2025 10:00 am	10/7/2025 12:00 pm
11	60-Page Midterm Report	11/3 or 11/5	TBD
12	Updated 60-Page Report	11/3 or 11/5	11/7/2025 12:00 pm
13	Final Optics Demo	11/18/2025 10:00 am	11/18/2025 12:00 pm
14	Final Document & Mini Demo Video	11/7/2025	11/25/2025 12:00 pm
Research & Hardware design			
15	Literature Review & Market Analysis	9/2/2025	9/12/2025
16	Microcontroller Comparisons (ATmega328, ATSAM3X8EA, STM32F303R8)	9/5/2025	9/19/2025
17	Preliminary Schematics & PCB layout	9/10/2025	9/26/2025
18	Communication Protocol Research (SPI, UART, I^2 C integration)	9/10/2025	9/29/2025
19	Peripheral Study (Bluetooth & LCD) and Motor & Driver Research	9/19/2025	10/1/2025
20	Power Supply Requirements & Regulator Selection	9/26/2025	10/5/2025

21	Safety & Risk Assessment (laser hazard class, eye protection)	9/26/2025	10/10/2025
22	Preliminary System Architecture (Block Diagrams, MCU role mapping)	10/3/2025	10/15/2025
23	Schematic Drafting (MCU + motor driver + laser circuits)	10/5/2025	10/15/2025
24	PCB layout (initial design for motor/laser subsystems)	10/8/2025	10/18/2025
25	Mechanical Gantry Design Research	10/15/2025	10/22/2025
26	Part Ordering & Verification	10/24/2025	11/12/2025

Appendix

Academic Resources

1. *SD2 Final Document - Group 2.docx*. (n.d.). Google Docs. https://drive.google.com/file/d/1-9XSiKTDrBUXfLMQIur1FekS7HH15aY3/view
2. Alhashem, M., Bayonis, A., Yuan, Y., Bennett, C., & Individual. (n.d.). *US20140267533A1 - Inkless printer - Google Patents*. https://patents.google.com/patent/US20140267533A1/en
3. Patil, Y., & Singla, A. (2023). LASER ENGRAVING PROCESS PARAMETER OPTIMIZATION FOR VARIOUS MATERIALS - A SYSTEMATIC REVIEW. In *Anveshana's International Journal of Research in Engineering and Applied Sciences* (Vol. 8, Issue 5). https://publications.anveshanaindia.com/wp-content/uploads/2023/05/LASER-ENGRAVING-PROCESS-PARAMETER-OPTIMIZATION-FOR-VARIOUS-MATERIALS-A-SYSTEMATIC-REVIEW.pdf
4. X. Lei, S. Liu, N. Wu, Y. Ge, H. Hou, and P. Liu, "Experimental investigation of laser engraving quality on paper," Applied Optics, vol. 59, no. 8, pp. 2416-2421, Mar. 2020. doi:10.1364/AO.377221. https://pubmed.ncbi.nlm.nih.gov/32225776

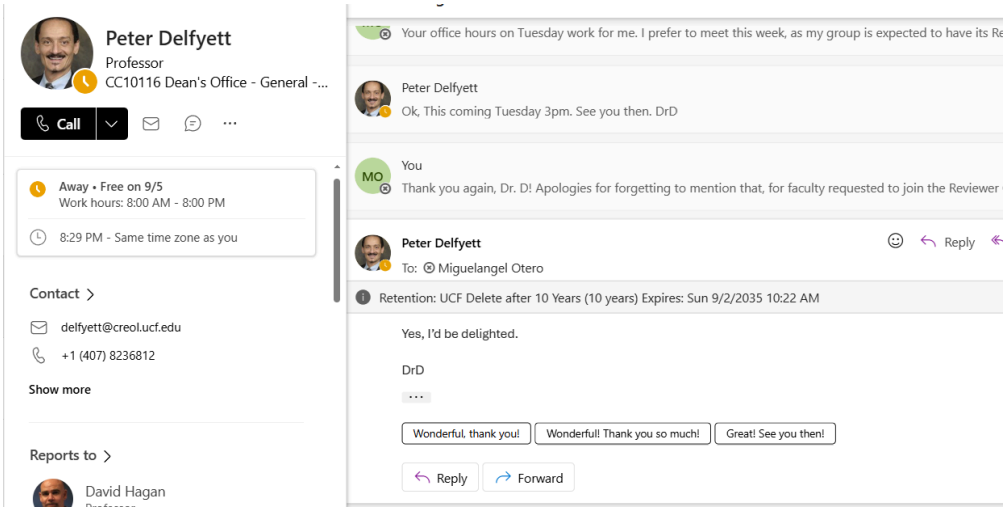
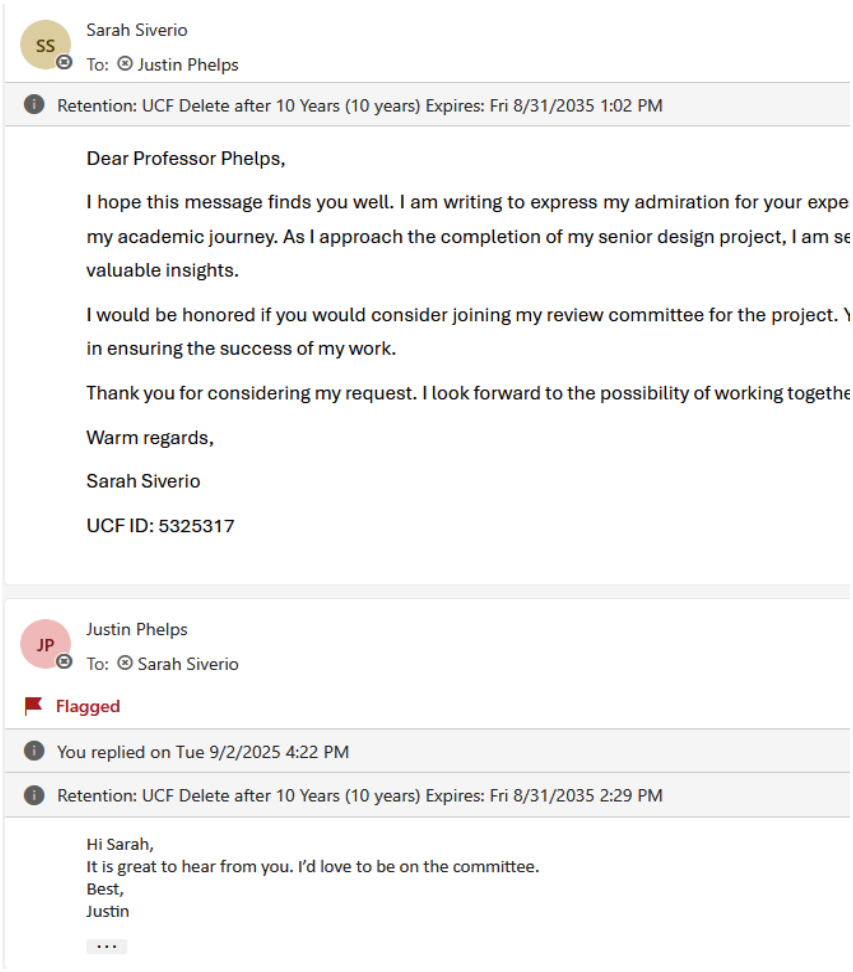
Planned Parts Links

5. Previous Group Website on Project: Home | Sd2g2
6. Product of LaserJet Printer & Cost: HP Laserjet
7. Document on HP LaserJet Printers in a consumer setting: How LaserJet Printers Work: Science Behind Fast Printing | HP® Tech Takes - Indonesia

8. PCB Supplier: https://jlcpcb.com
9. Plastic Aspheric Lens(ordered): https://www.thorlabs.com/thorproduct.cfm?partnumber=CAW100-A
10. Plano-Convex Lens(ordered): https://www.thorlabs.com/thorproduct.cfm?partnumber=LA1270-A
11. Laser Goggles (can be borrowed?): https://www.sanwulasers.com/product/goggles
12. Laser Diode(ordered): https://lasertree.com/products/sharp-gh05280e2k-%CF%865-6mm-green-520nm-80mw-laser-diode?_pos=6&_fid=ae46e9212&_ss=c
13. LD Heatsink (ordered): https://odicforce.com/epages/05c54fb6-7778-4d36-adc0-0098b2af7c4e.mobile/?ObjectPath=/Shops/05c54fb6-7778-4d36-adc0-0098b2af7c4e/Products/OFL117&ClassicView=1
14. Back up fan: https://www.bestbuy.com/site/fans-cooling-kits/cpu-fans-heatsinks/pcmcat339900050006.c?id=pcmcat339900050006
15. LD Driver: https://www.thorlabs.com/thorproduct.cfm?partnumber=LDS9
16. LD Socket (ordered): https://www.thorlabs.com/thorproduct.cfm?partnumber=S7060R
17. Raspberry Pi: https://www.digikey.com/en/products/detail/raspberry-pi/SC0563/6235381
18. Power Supply: https://www.digikey.com/short/n18qqmdz
19. Aluminum Rails: https://amzn.asia/d/7REWg0L
20. X and Y axis motors: https://a.co/d/2rr3pQX
21. Bolts and Nuts: https://boltdepot.com/Product-Details?product=6259
22. Paper Feed Motor: https://nfpmotor.com/25mm-metal-gear-motor-model-nfp-jga25-370-en
23. Paper: https://a.co/d/2wlyhOd

Email Confirmations

- Dr. Delfyett:



- Dr. Justin Phelps