ECE 445

Polynomial Texture Mapping Dome

By:

Priya Dutta

Sam Mencimer

Nick Mitchell

Final Report for ECE 445, Senior Design, Spring 2025

TA: Eric Tang

May 7, 2025

Team 22

Abstract

This project presents the restoration and redesign of a Polynomial Texture Mapping (PTM) dome system used by the Spurlock Museum to digitally preserve cultural artifacts. The system captures 32 photographs of an object, each illuminated from a unique direction, enabling surface detail analysis. We developed a custom PCB for LED control, integrated camera synchronization, a user-friendly GUI, and a robust 3D-printed enclosure. The final system operates reliably in both manual and automatic modes and includes repair documentation to support long-term use.

Contents

1. Introduction

1.1 Problem

The Spurlock Museum uses a PTM dome to digitally capture surface textures of fragile artifacts through directional lighting. However, their previous dome system had become non-functional due to obsolete components, unreliable LED behavior, and compatibility issues with modern computers. The museum required a robust replacement system that was easy to operate, maintain, and repair without requiring technical expertise.

1.2 Solution

Our team developed a fully functional PTM dome control system with three major components: a custom LED control PCB, a cross-platform graphical user interface, and a modular hardware enclosure. The PCB controls 32 high-powered LEDs and opto-isolates the camera trigger signal for synchronized image capture. The GUI allows for both automatic and manual lighting control. Custom LED units and a heat-resistant, labeled enclosure were designed to simplify future repairs and replacements. The system is reliable, easy to use, and ready for long-term use in the museum environment.

1.3 High Level Requirements

- **Precise LED Sequencing and Control:** The system must be able to turn each of the 32 LEDs on and off in a controlled sequence, both manually and automatically. Each LED should maintain stable illumination without flickering or unintended activation of adjacent LEDs. Also, the user must be able to select and activate individual LEDs on command through the user interface in a separate mode of operation.
- **Accurate Camera Shutter Synchronization:** The camera must be triggered within 50ms of an LED turning on to ensure accurate image capture. The triggering. mechanism (a 3.5mm jack signal sent to the N3 port) must be stable and repeatable, ensuring that the camera does not miss or misfire during the sequencing process. This will require isolating the signal sent to the camera, and properly shielding the attached cable.
- **Long-Term Reliability and Stability:** The system must complete multiple full PTM capture cycles (a cycle includes activating all 32 LEDs and capturing corresponding images) without system crashes or desynchronization. The hardware (microcontroller, PCB, LED drivers) should maintain consistent performance without overheating or signal degradation. The system must function across multiple operating systems and remain compatible for at least a few years with minimal maintenance, ensuring long-term usability for museum staff.

To create a section head, go to the Styles gallery under the Home tab and pick Heading 2. It automatically formats as above and creates a table of contents entry (after you click the Update tab). Word will not make the capitalization consistent; you have to do that yourself.

Figure 1 is an example of figure and caption style. Table 1 is an example of table and table title style. A starter table for parts costs is in Chapter 4 of this template.

Use the References➔Insert Caption tool to generate consistently formatted captions (always *below* the figure), and use the grouping function in Word's drawing tools to hold figure and caption together. Use picture formatting tools to hold figures in place (preferably at top or bottom of page) and to define text wraps ("top and bottom" is best).

Use Word's table design and layout tools to format titles, column heads, and borders.

Insert page break at end of every chapter to ensure next chapter starts on new page.

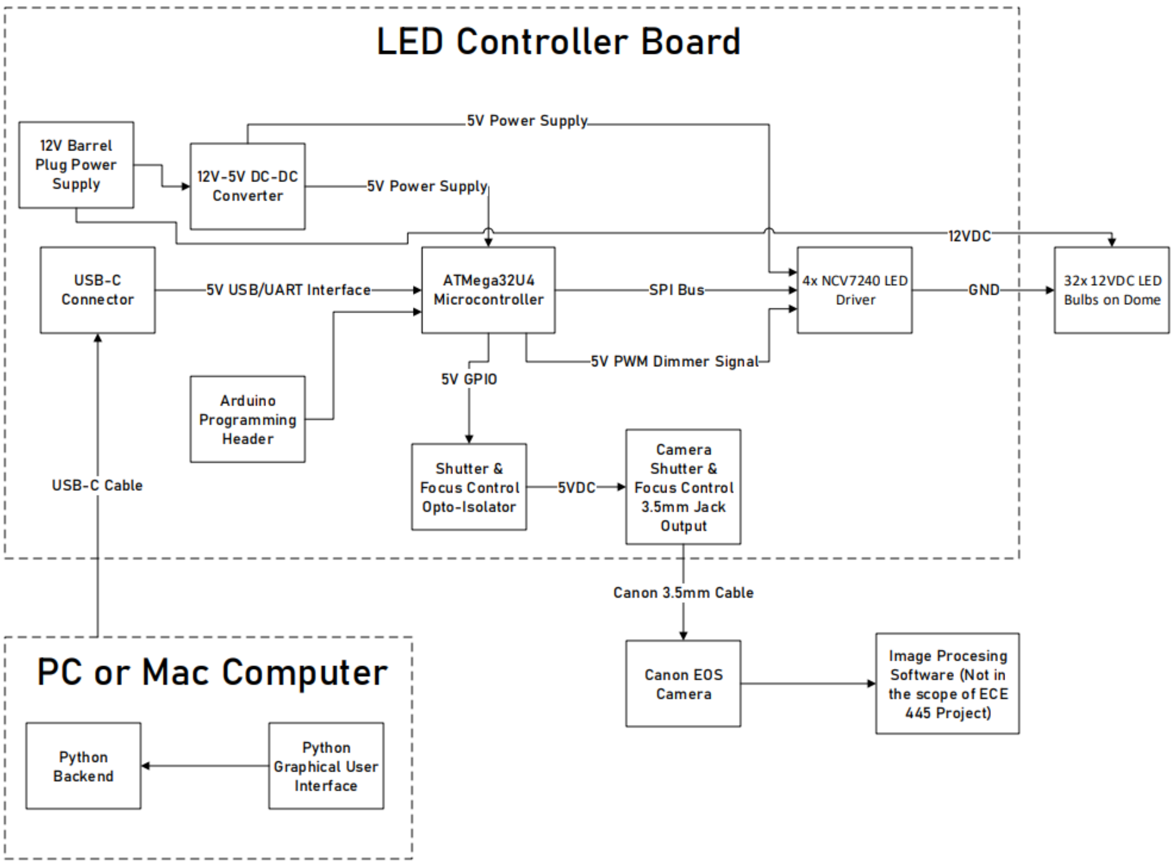

Figure 1 - PTM Dome Block Diagram

2. Design

Discuss general design alternatives. Give equations, simulations, general circuits. Describe design in detail, addressing each major component. Include schematics with components, drawings, flowcharts, etc. Some teams may wish to split this chapter in two: 2. Design Procedure, and 3. Design Details. This template will not automatically update numbering systems for chapters, sections, figures, tables, etc., so keep track of them as you develop and revise the text.

Following is a “template” for displayed math. Use the MathType extension of Word to generate your own content, and note the use of the invisible table (no borders) to keep the optional number flush right.

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LEDs and Wiring

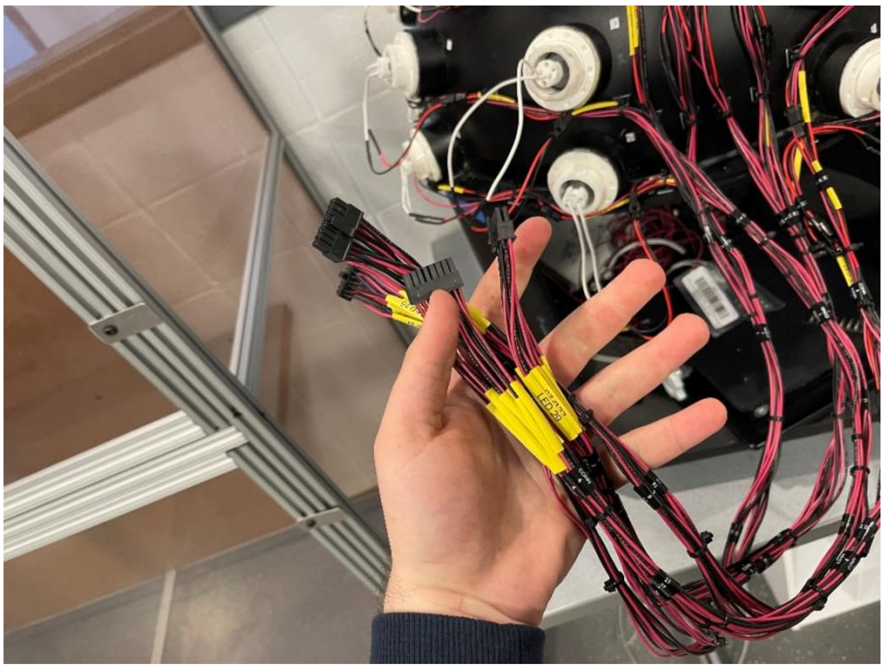

Figure 2 - LED Connectors on PTM Dome

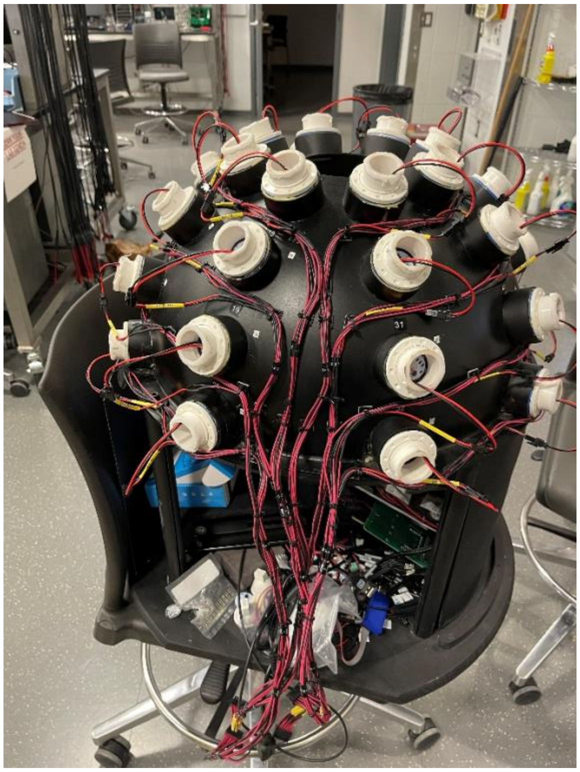

Figure 3 - Completed Wiring on PTM Dome

2.1.1 [Subcomponent or subblock]

To create a subsection head, go to the Styles gallery under the Home tab and pick Heading 3. It automatically formats as above and creates a table of contents entry (after you click the Update tab). Even lower level section heads can be created the same way, but they are likely unnecessary.

PCB Design

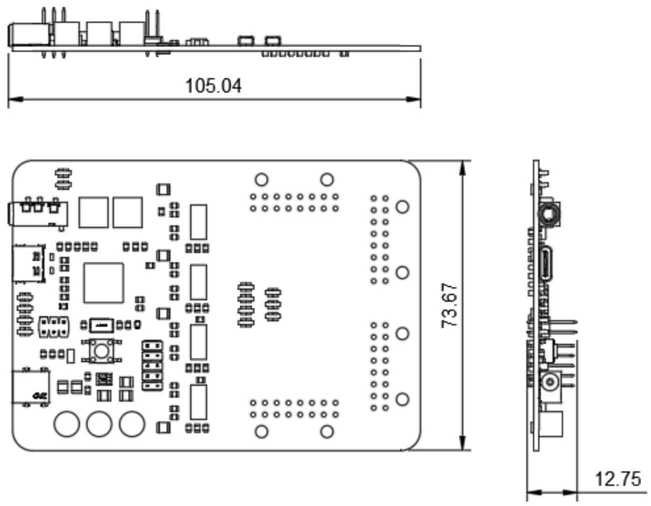

Figure 4 - PCB Dimensions

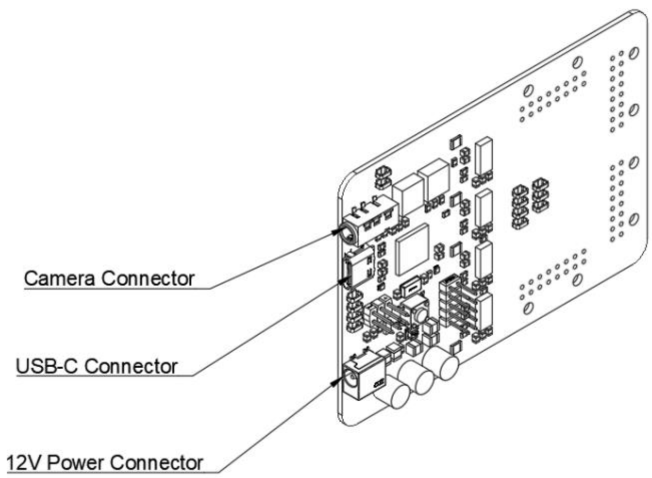

Figure 5 - Interface Connectors

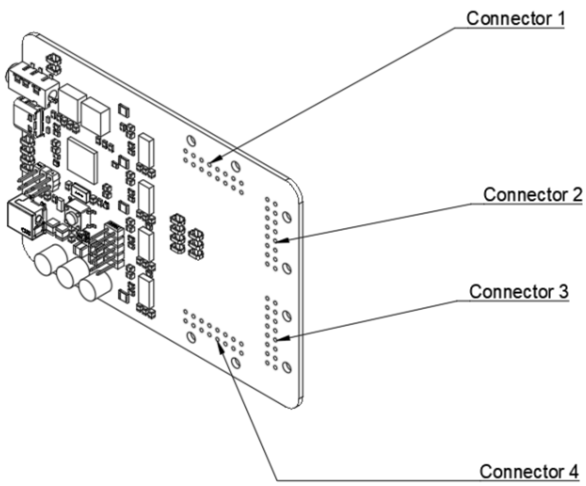

Figure 6 - LED Connectors

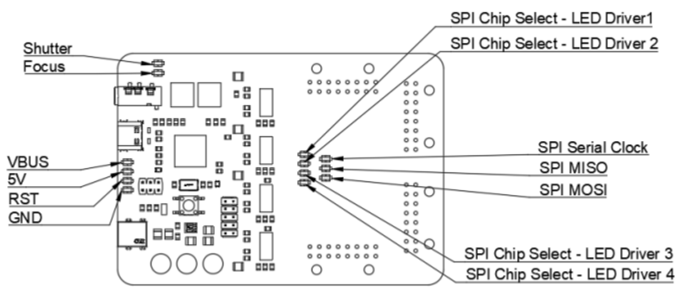

Figure 7 - Test Points

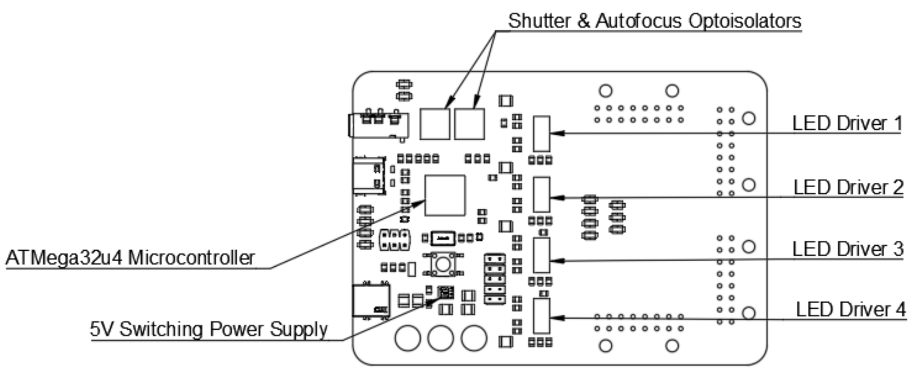

Figure 8 - Integrated Circuits

Microcontroller

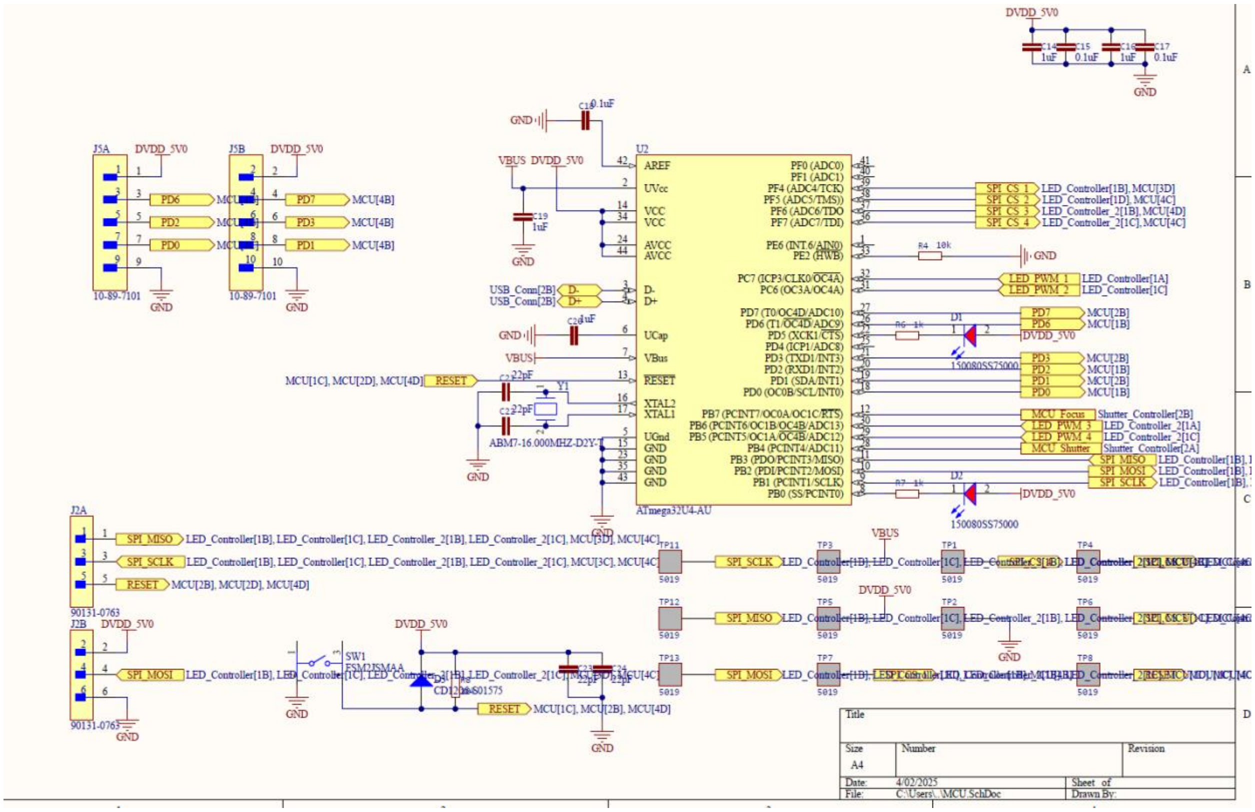

Figure 9 - Microcontroller Schematic

LED Drivers

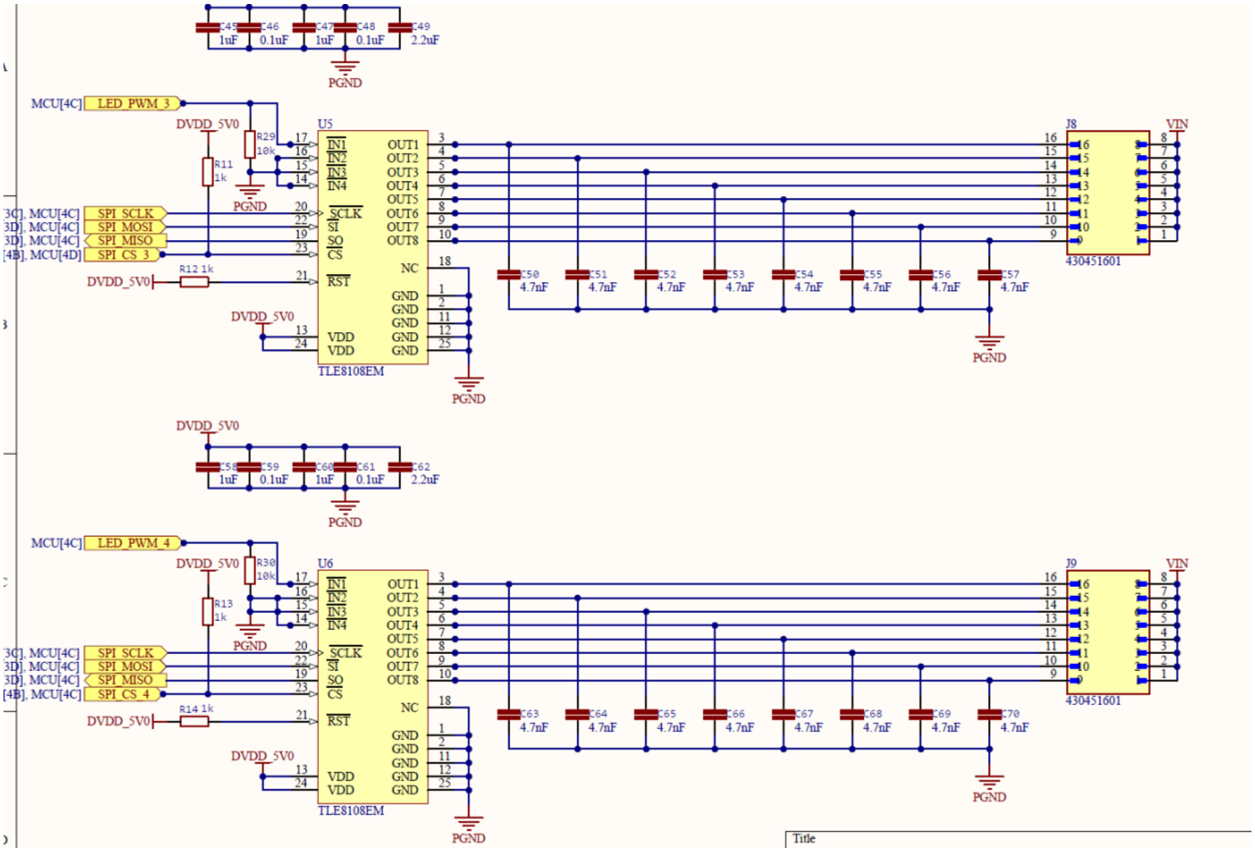

Figure 10 - LED Driver Schematic

Power Supply

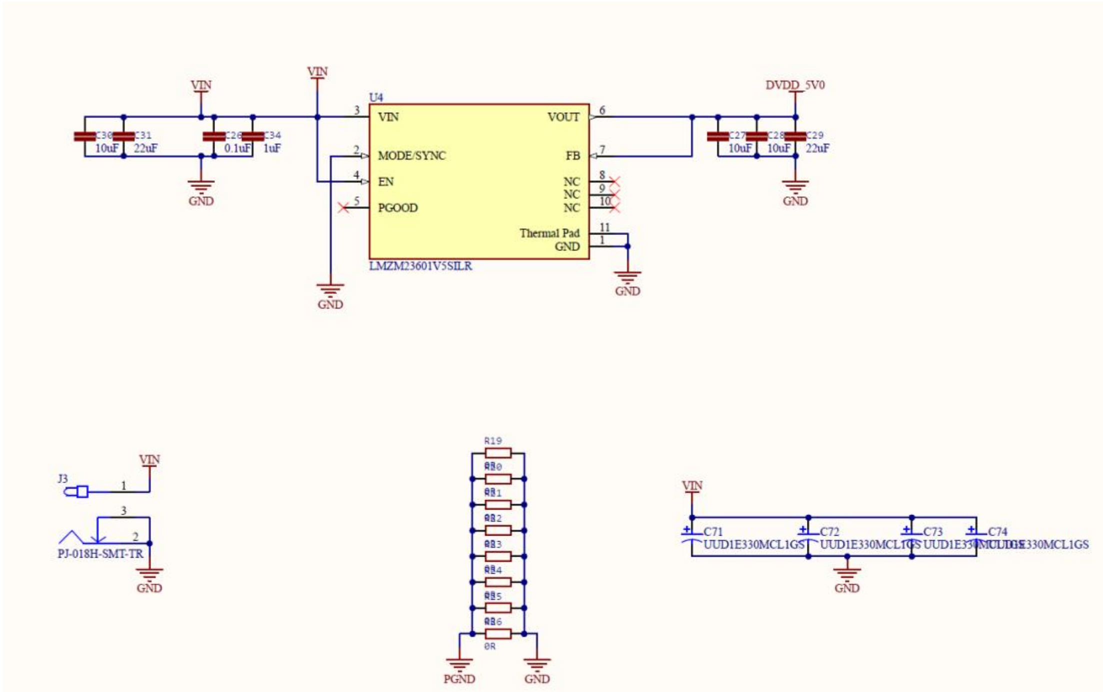

Figure 11 - Power Supply Schematic

Software & GUI

Longevity & Repairability

Control Enclosure

3. Design Verification

Insert text.

3.1 [Component or Block]

Insert text.

3.1.1 [Subcomponent or subblock]

Insert text.

4. Costs

4.1 Parts

Table 1 – Parts Cost Table

Component Type	Value/Part Number	Description	Quantity	Unit Price	Extended Price
Board	1uF	Generic 0805 SMD capacitor	13	0.1	1.3
Board	0.1uF	Generic 0805 SMD capacitor	12	0.1	1.2
Board	2.2uF	Generic 0805 SMD capacitor	4	0.1	0.4
Board	4.7nF	Generic 0805 SMD capacitor	32	0.08	2.56
Board	22pF	Generic 0805 SMD capacitor	4	0.04	0.16
Board	10uF	Generic 1210 SMD capacitor	3	0.172	0.516
Board	22uF	Generic 1210 SMD capacitor	2	0.112	0.224
Board	UUD1E330MCL1GS	Aluminum Electrolytic Capacitor, UD Series, Low Impedance, 33 uF, 25 V, + / - 20%, -55 to 105 degC, Chip Type, 6.3 x 5.8 mm D x L, Pb-Free, Reel	4	0.53	2.12
Board	150080SS75000	Led, Red, 630 Nm, 1.9 V, 30 Ma, 60 Mcd Rohs Compliant: Yes	2	0.17	0.34
Board	CD1206-S01575	75 V Small Signal Switching Diode, 150 mA, 2.5 uA, 1026 Molded Package, RoHS, Tape and Reel	1	0.053	0.053
Board	4N26-X009T	Transistor Output Optocoupler, 1-Element, 5300V Isolation	2	0.528	1.056
Board	105450-0101	USB Connector, 24 Contact(s), Female, Right Angle, Surface Mount Terminal, Receptacle	1	2.55	2.55
Board	90131-0763	90131-0763 Conn Unshrouded Header HDR 6 POS 2.54mm Solder ST Top Entry Thru-Hole C-Grid III™ Tray	1	0.5	0.5
Board	54-00165	CONN JACK R/A SMT 5.5X2.5MM	1	0.91	0.91
Board	SJ2-3574A-SMT-TR	AUDIO JACK, 3.5 MM, RT, 4 CONDUC	1	0.87	0.87
Board	10-89-7101	CONN HEADER VERT 10POS 2.54MM	1	0.5	0.5
Board	430451601	CONN HEADER R/A 16POS 3MM	4	3.87	15.48
Board	1k	Generic 0805 SMD Resistor	10	0.1	1
Board	22R	Generic 0805 SMD Resistor	2	0.1	0.2
Board	10k	Generic 0805 SMD Resistor	8	0.1	0.8
Board	220R	Generic 0805 SMD Resistor	2	0.1	0.2
Board	0R	Generic 0805 SMD Resistor	2	0.1	0.2
Board	0R	Generic 1210 SMD Resistor	8	0.1	0.8
Board	CG0603MLC-05E	ESD Protector, 5 V Supply, -40 to 85 degC, 1.6 x 0.8 x 0.55 mm SMD, RoHS, Tape and Reel	2	0.307	0.614

Board	FSM2JSMAA	SWITCH TACTILE SPST-NO 0.05A 24V	1	0.201	0.201
Board	5019	Phosphor Bronze Contact Miniature Silver Plated Surface Mount Test Points	13	0.26	3.38
Board	TLE8108EM	Smart 8 Channel Low Side Relay Driver with SPI Interface with Limitation Over-Current Protection, -40 to 150 degC, PG-SSOP-24-4, Reel, Green	4	3.31	13.24
Board	ATmega32U4-AU	8-bit AVR Microcontroller, 2.7-5.5V, 16MHz, 32KB Flash, 1KB EEPROM, 2.5KB SRAM, USB Controller, 44-pin TQFP, Industrial Grade (-40°C to 85°C), Ext Osc	1	5.29	5.29
Board	LMZM23601V5SILR	DC DC CONVERTER 5V	1	5.17	5.17
Board	ABM7-16.000MHZ-D2Y-T	Crystal 16MHz ±20ppm 18pF SMD-2 6mm x 3.5mm	1	0.66	0.66
Dome	Wire	Dome Wiring -1 ft	100	0	0
Dome	430251600	CONN RCPT HSG 16POS 3.00MM	4	1.05	4.2
Dome	430300051	Molex Female Micro-Fit 3.0 ™ Crimp Terminals Pins Wire Diameter: 20-24awg, 1.85 mm	64	0.141	9.024
Bulb	B09N3PC1RR	G4 Bi Pin Base 10W 15W Halogen Replacement Bulb 24-2835SMD LED - 3000K Warm White	32	1.16	37.12
Dome/Bulb	4330128506	22 AWG JST SM 2 Pin Plug Male and Female Connector Adapter with 135 mm Electrical Cable Wire for LED Light	32	0.37	11.84
Power Supply	GST60A12-P1M	AC/DC DESKTOP ADAPTER 12V 60W	1	20.61	20.61
Power Supply Cable	AC30UNA	CORD NEMA5-15P - IEC 320-C13 6'	1	6.36	6.36
			Total		$151.64

4.2 Labor

Labor costs were estimated based on an hourly rate of $40, reflecting the skill level of ECE program graduates. A multiplier of 2.5 was used to account for overhead costs such as benefits and administrative expenses. Each team member contributed approximately 80 hours to the project. At 80 hours per person, the total adjusted labor cost per team member was $3200 x 2.5 = $8,000, resulting in a total estimated labor cost of $24,000. This reflects the time and effort dedicated to system design, prototyping, testing, and documentation.

5. Conclusion

5.1 Accomplishments

Our project successfully delivered a fully functional PTM dome system that meets all core functional and reliability goals. We designed a custom PCB capable of controlling 32 high-power LEDs with precise timing and opto-isolated camera synchronization. A cross-platform Python GUI was developed to offer both manual and automatic imaging modes, and the entire system is housed in a custom 3D-printed enclosure engineered for thermal management, physical protection, and long-term serviceability. The system was tested, and it performed consistently. A complete set of user and repair documentation was also produced. The Spurlock Museum now has a working, maintainable system ready for artifact digitization.

5.2 Uncertainties

Although the final system is functional, there were elements that remain either untested or incomplete due to time/resource limitations. One such area was LED PWM dimming; while the PCB supports PWM output lines, the signals on the first print of the PCB were routed together and did not allow for individual brightness control. The re-printed version of the PCB should, in theory, be able to support LED dimming but we weren't able to test it because it arrived in the last few weeks of the semester. Additionally, while our project is designed for ease of use, usability testing with museum staff was not completed before submission. Finally, although we printed the control enclosure in PLA, we had originally planned to use PETG for better thermal and impact resistance but were limited by material availability.

5.3 Ethical considerations

In accordance with the IEEE Code of Ethics [1], we ensured the system is safe, enclosed, and user-friendly to minimize electrical and mechanical risks to users. All connectors are clearly labeled, physical access to circuitry is restricted through enclosure design, and comprehensive documentation supports safe, long-term use and maintenance. These considerations align with our ethical obligation to hold paramount the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment, as stated in Sections I.1 and I.9 of the IEEE Code of Ethics.

5.4 Future work

Recommendations for Improvements include separating PWM control lines on the PCB for independent dimming, coating the enclosure in ESD-resistant paint for added static protection, reprinting the enclosure in PETG for better thermal and impact performance, extending GUI functionality to support brightness control, and testing and tuning enclosure thermals under full load for better reliability.

References

[1] IEEE, "IEEE Code of Ethics," IEEE, 2020. [Online]. Available at: https://www.ieee.org/about/corporate/governance/p7-8.html

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[7] S. Al Kuran, “The prospects for GaAs MESFET technology in dc–ac voltage conversion,” in *Proceedings of the Fourteenth Annual Portable Design Conference*, 2010, pp. 137-142.

[8] K. E. Elliott and C. M. Greene, “A local adaptive protocol,” Argonne National Laboratory, Argonne, IL, Tech. Rep. 916-1010-BB, 2006.

[9] J. Groeppelhaus, “Java 5.7 tutorial: Design of a full adder,” class notes for ECE 290, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, 2011.

Appendix A Requirement and Verification Table

Table 2 - System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. LED Controller Board		
a. Must maintain stability with up to 8 LEDs on simultaneously.	a. Turn on 8 LEDs simultaneously using PC software and verify that current draw on the 12V circuit does not exceed 80% of the rating of the AC Adapter and the LEDs stay illuminated for at least 1 minute without causing damage or excessive heat.	Y
b. Camera ground must be electrically isolated from system ground	b. Measure resistance between camera ground and PCB ground using a multimeter. Confirm "OL" or resistance greater than 1MΩ.	Y
c. Control 32 12V LED Outputs individually through Arduino software.	c. Test signal sent from PC User Interface enables each LED individually.	Y
d. Connect to PC via USB-C Cable	d. PC can successfully communicate with the MCU firmware via the USB-C cable.	Y
2. User Interface		
a. Manual LED control must function correctly.	a. Use GUI manual mode to turn LEDs on and off individually. Confirm correct operation visually.	Y
b. The system must provide clear visual feedback for LED states and display real-time connection status. It must also display error messages when communication fails	b. UI correctly updates based on microcontroller feedback. Simulate communication failure and verify the correct error message appears	Y
c. The GUI and PCB must not cause any dome motion during operation.	c. The dome does not move during operation. The PCB is attached to the dome base to prevent any movement.	Y
3. LED Lights and Dome		

a. LEDs and sockets must be replaceable without tools.	a. Replace an operational LED and a socket with a provided spare without tools. Confirm system operates normally.	Y
b. Single LED must draw less than 300mA at 12V.	d. Measure current draw for a single LED.	Y – 92mA
4: Longevity and Repairability		
a. A user manual shall be provided which encompasses all aspects of normal device operation.	a. User manual will be provided to a person unfamiliar with the project. They will be able to fully execute all instructions.	Y – Edits with input from Spurlock in progress
b. The system must provide clear visual feedback for LED states and display real-time connection status. It must also display error messages when communication fails	b. The troubleshooting & repair manual will be provided to a person unfamiliar with the project. They will be able to fully execute all instructions.	Y
c. All components shall be assembled using standard fasteners. No glue shall be used in the assembly, except for the dome structure or for any pieces which are not reasonably expected to fail.	c. Disassemble and reassemble the system three times using only screwdrivers. Confirm no mechanical failure or cracks.	Y
d. Spare parts will be provided to ensure system longevity.	d. At least one spare of each replaceable component provided	Y
e. The microcontroller must support embedded Arduino programming for long-term flexibility.	e. ATMega32u4 supports Arduino.	Y
5: Control Enclosure		
a. Enclosure must survive minor impacts.	a. Drop the enclosure from a height of 1 foot onto carpet and inspect for cracks, connector loosening, or cosmetic damage.	Y
b. Connectors must be clearly labeled.	b. Visually inspect the system and verify that all external ports are labeled and	Y

		readable from a normal operating distance.	
c. Components inside the enclosure can be replaced several times without damage to the enclosure		c. Ensure all standoffs are metal.Install/remove control board three times and ensure no wear on the enclosure.	Y
d. Enclosure can be disassembled with a standard screwdriver.		d. Verify all connections are made with standard fasteners.	Y