ECE 445 Team 22 - SP25

Spurlock PTM Dome Design Document

Professor: Arne Fliflet
TA: Eric Tang

Sam Mencimer (sgm8)
Priya Dutta (dutta15)
Nick Mitchell (nlm4)

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1.Introduction

1.1 Problem

The Spurlock Museum has long been committed to the digital preservation of artifacts, enabling researchers worldwide to study historical objects without the risk of physical handling. A key component of this effort has been the use of a Polynomial Texture Mapping (PTM) dome, a specialized imaging system that captures high-detail images of artifacts under varying lighting conditions. This technology allows researchers to analyze surface details that may not be visible under standard lighting, enhancing historical and archaeological studies.

Originally constructed in 2008 with technology dating back to 2001, the PTM dome is operated by sequentially illuminating an artifact with 32 LEDs, capturing a corresponding set of 32 images. These images are then processed externally to generate 3D images of artifacts. However, as the system aged, it became non-functional, halting the museum's digital preservation efforts. In response, two previous ECE 445 teams attempted to restore the system, successfully fabricating a dome structure and developing a partially functional graphical user interface (GUI) for control. Despite this, the primary issue preventing full restoration is the failure of the PCB that integrates LED control with the camera shutter. This missing functionality prevents the dome from sequencing the lighting and capturing synchronized images, which makes it unusable.

Our project aims to complete the restoration by designing and implementing a fully functional PCB that enables proper communication between the LEDs and the camera system. Additionally, we will conduct thorough system testing to ensure the dome's long-term reliability. Beyond the technical implementation, our project will also address usability and maintainability. We will document our design thoroughly, ensuring that future teams at Spurlock can easily modify or repair the system if needed. Testing will include not only functional validation but also stress testing to simulate prolonged operation, ensuring the dome can support long-term use without frequent maintenance. Ultimately, our goal is to ensure that the museum has a robust and reliable digital preservation tool.

1.2 Solution

This project is rather unique because the solution has mostly been developed previously. Our role is to complete the project to present a functional PTM dome to the museum. This will involve redesigning the PCB to control the 32 LEDs in the existing dome as per the museum's requirements, developing manuals and troubleshooting instructions, and testing the dome to ensure full functionality. Our PCB will be required to have two modes of operation: (1) individually toggling LEDs to photograph objects within the dome, and (2) taking a sequence of 32 images by controlling the camera shutter and toggling each corresponding LED.

The novelty of our solution lies in its integration and reliability. While previous teams have laid the groundwork, we will finalize the system to ensure a completely functional and sustainable solution. Unlike prior implementations, our design with a re-designed PCB will ensure seamless communication between the LEDs and the camera. We also intend to completely scrap the wiring for the LEDs used by the previous group and implement a more robust version. Additionally, our rigorous testing process will validate long-term functionality, reducing the need for future repairs or redesigns.

Another key improvement is the usability of the system. By making user-friendly design choices and developing comprehensive manuals and troubleshooting documentation, we will ensure that museum staff and researchers can operate the system without requiring extensive technical expertise. Ultimately, our goal is to transform the PTM dome from a partially restored system into a fully operational, reliable tool that will enable the Spurlock Museum to resume its artifact preservation efforts effectively.

1.3 Visual Aid

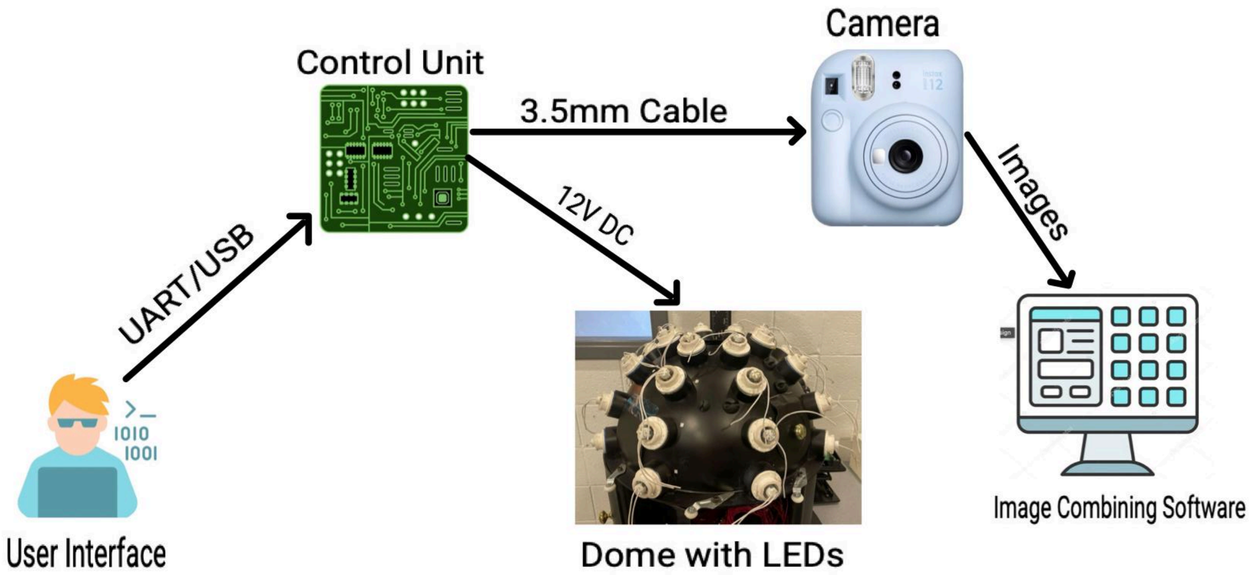


Figure 1, Visual aid for connections between system components

This figure illustrates the system architecture for our project. The user interface communicates with the control unit via UART/USB, which controls both the dome's LEDs (via SPI) and the camera (via a 3.5mm cable). The camera captures images under different lighting conditions, which are then processed using an image combining software provided by the Spurlock Museum. This software is not part of our project.

1.4 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 or 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.

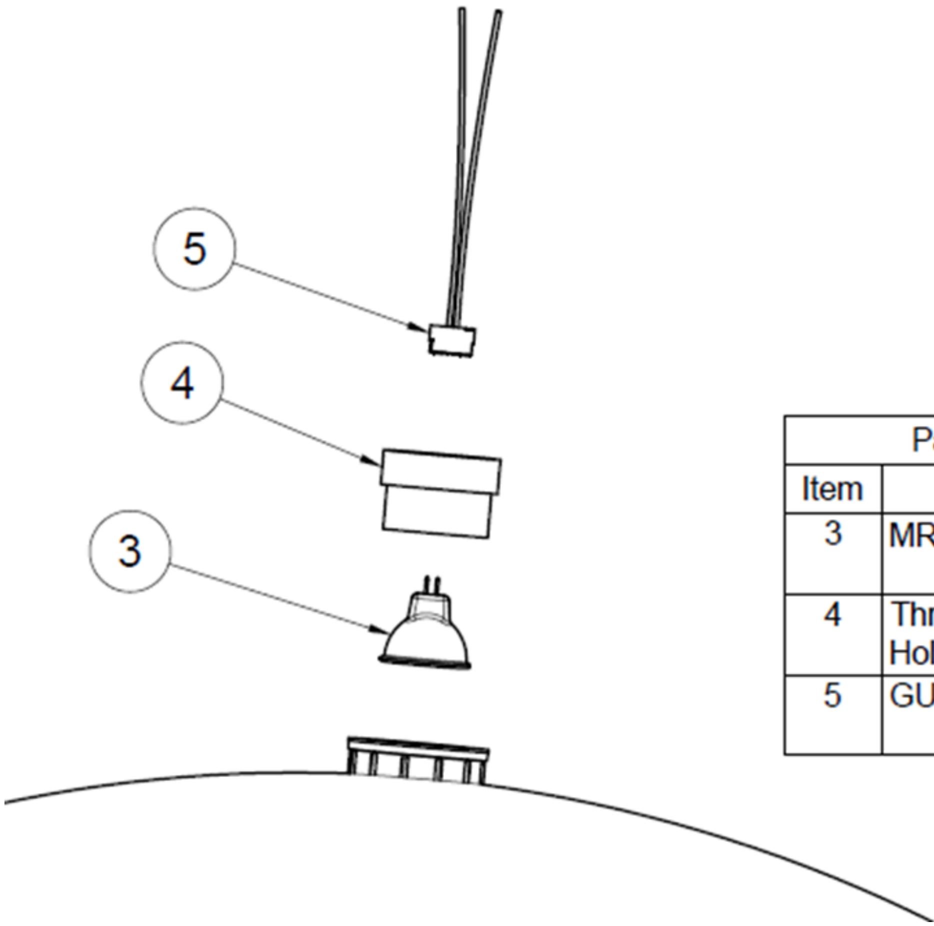
- **Accurate Camera Shutter Synchronization:** The camera must be triggered within 50ms of an LED turning on to ensure accurate image capture. The triggering mechanism (a 3.5mm jack signal sent to the N3 port) must be stable and repeatable, ensuring that the camera does not miss or misfire during the 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 at least 100 consecutive 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.

2. Design

2.1 Physical Design

The system will consist of a dome manufactured from black plastic, with a sliding door on the front. There are 32 LED holders on top of the dome, and a hole in the center for the camera to take images through. The LEDs are connected to sockets, which connect to wires on the dome with 2-pin JST connectors. Each wire will be labeled with a number 1-32 for easy identification.

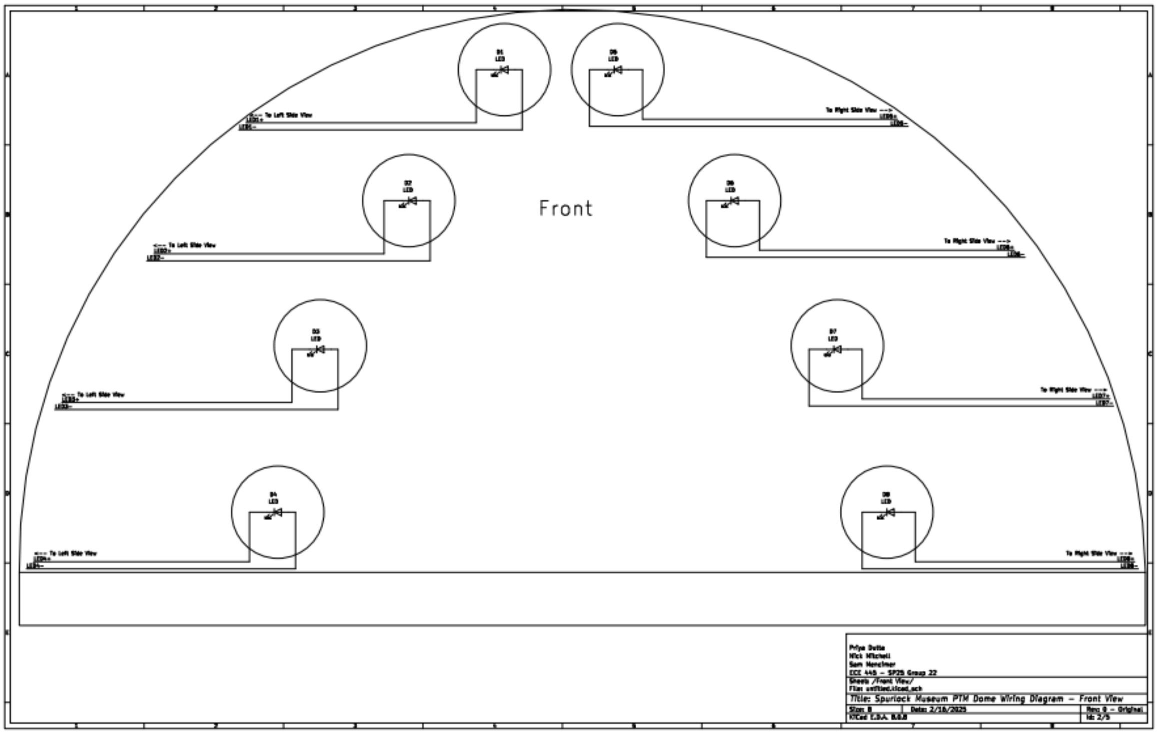
Bulb assembly diagram:

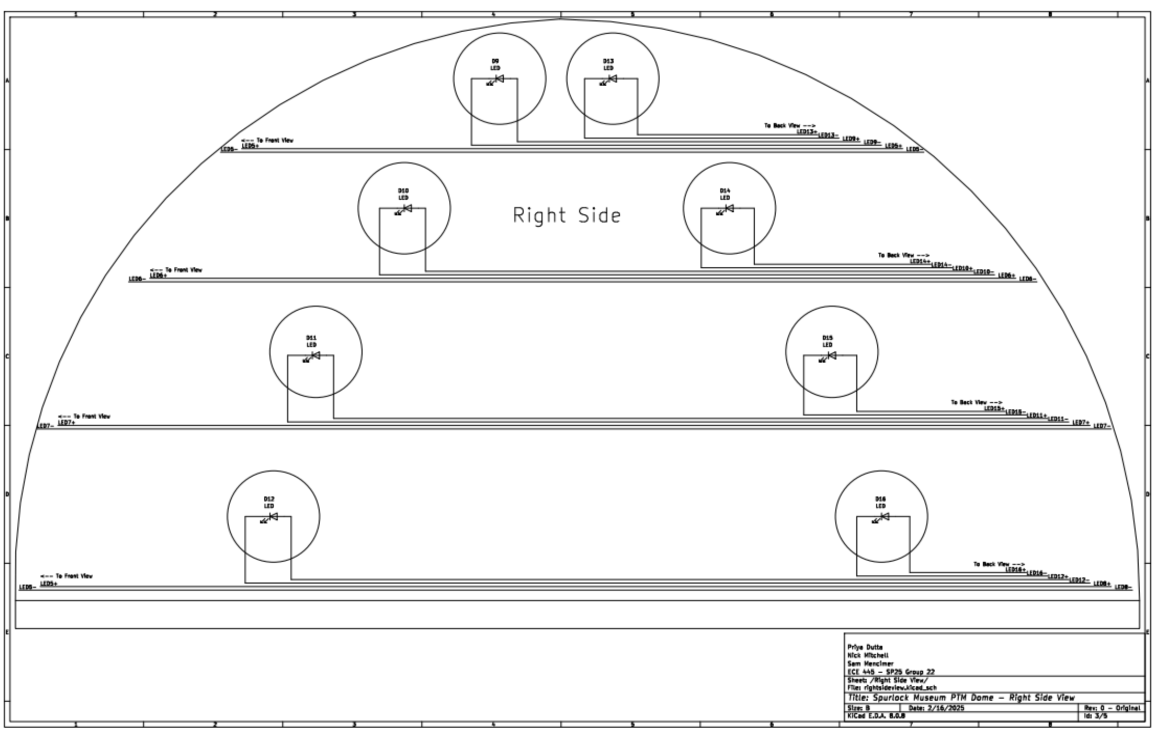


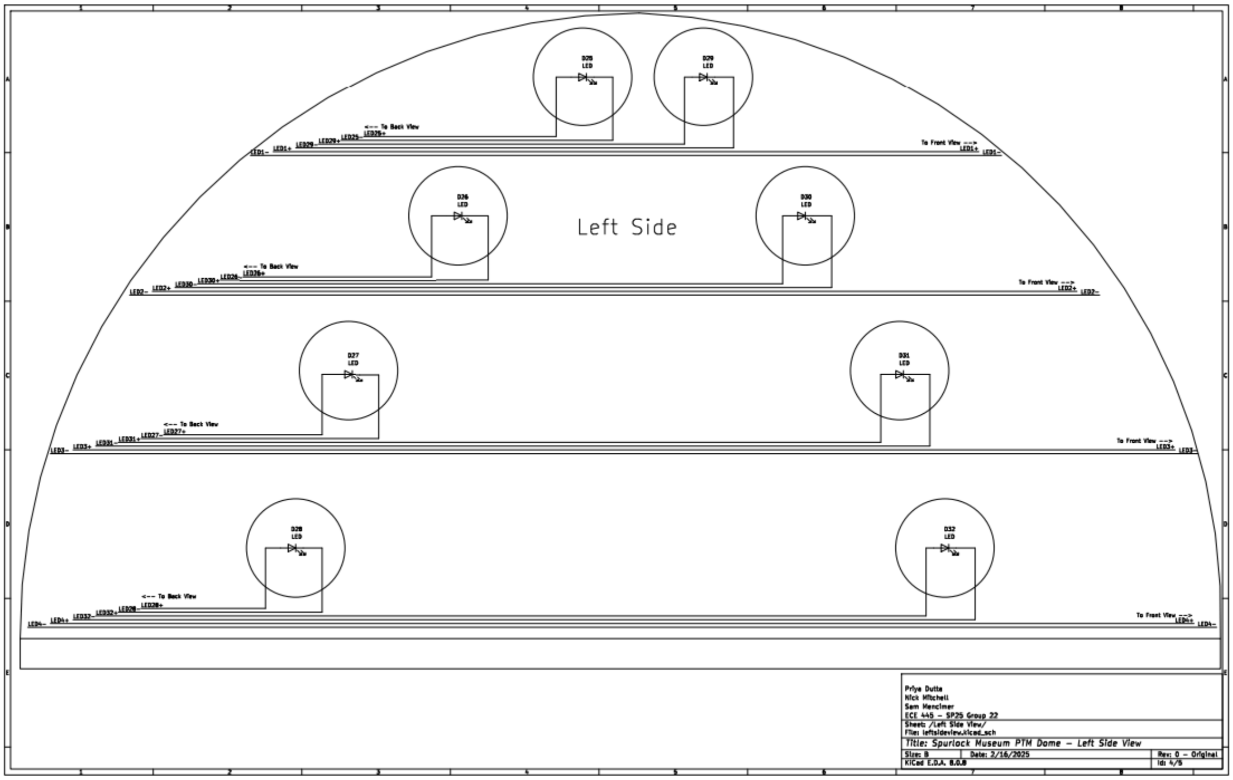
Parts List	
Item	Part Name
3	MR11 LED Bulb
4	Threaded Bulb Holder
5	GU4 Bulb Socket

Photo of dome for reference:

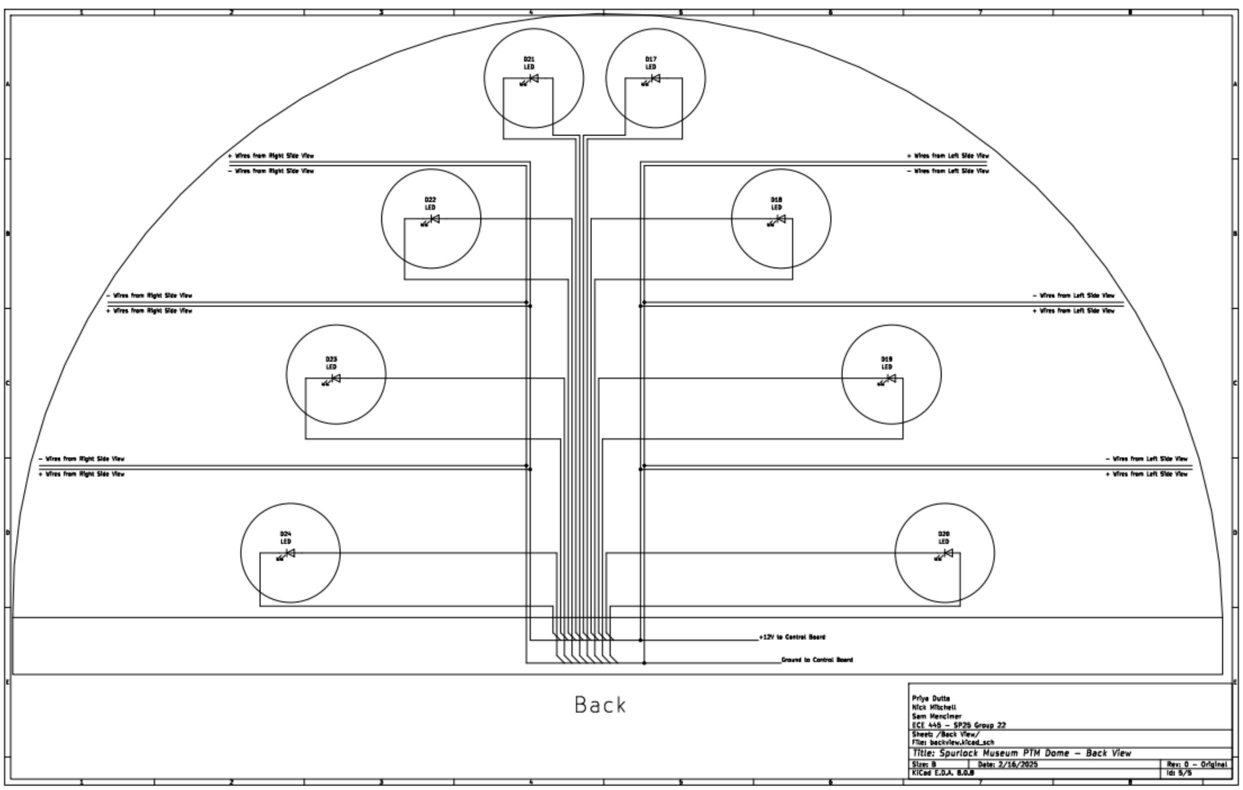
The wiring will be run according to the following diagram:







Left Side
D25
LED
D29
LED
D26
LED
D30
LED
D27
LED
D31
LED
D28
LED
D32
LED
<-- To Back View
To Front View -->
Priya Dutta
Nick Mitchell
Sam Mencimer
ECE 445 - SP25 Group 22
Sheet: /Left Side View/
File: leftsideview.kicad_sch
Title: Spurlock Museum PTM Dome - Left Side View
Size: B
Date: 2/16/2025
Rev: 0 - Original
KiCad E.D.A. 8.0.8
Id: 4/5



D21
LED
D17
LED
D22
LED
D18
LED
D23
LED
D19
LED
D24
LED
D20
LED
+ Wires from Right Side View
- Wires from Right Side View
+ Wires from Left Side View
- Wires from Left Side View
+12V to Control Board
Ground to Control Board
Back
Priya Dutta
Nick Mitchell
Sam Mencimer
ECE 445 - SP25 Group 22
Sheet: /Back View/
File: backview.kicad_sch
Title: Spurlock Museum PTM Dome - Back View
Size: B
Date: 2/16/2025
Rev: 0 - Original
KiCad E.D.A. 8.0.8
Id: 5/5

The ends of the wires will connect to 4 16-pin Molex MicroFit 3.0 connectors, which plug into the controller board.

The controller board will be housed in an enclosure with holes for all required connectors.

2.2 Block Diagram

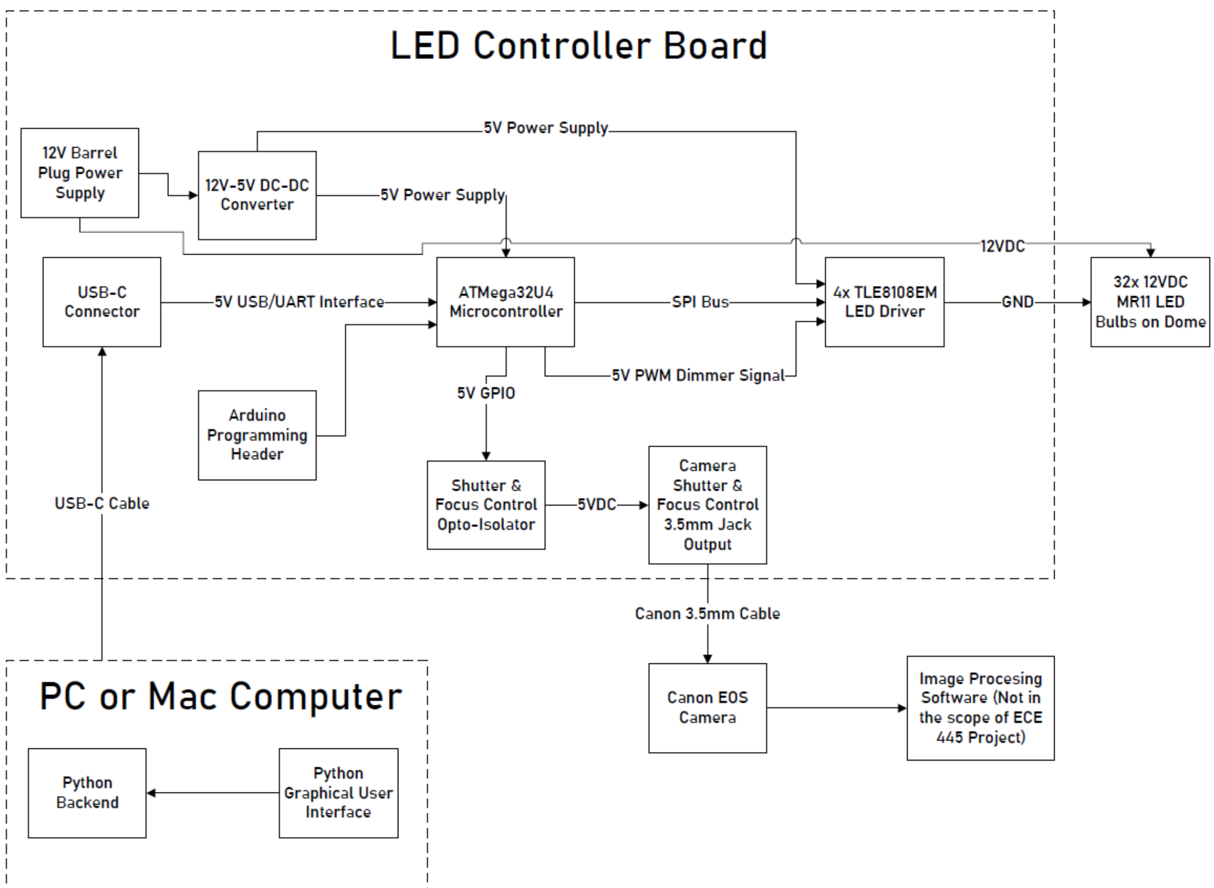


Figure 2 - Block diagram of the entire system. Signals are labeled along each arrow

2.3 Functional Overview & Block Diagram Requirements

2.3.1 Subsystem 1 - LED Controller Board

Requirement	**Verification**
Control 32 12V LED Outputs individually through Arduino software.	Test signal sent from PC User Interface enables each LED individually.
Connect to PC via USB-C Cable	PC is able to successfully communicate with the MCU firmware via the USB-C Cable.
Maintain stability with up to 8 LEDs turned on simultaneously	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 60W AC Adapter and the LEDs stay illuminated for at least 1 minute without causing damage or excessive heat.
Opto-isolation between camera control and PCB	Measure resistance between GND on camera output and GND plane for the rest of the PCB. Verify very high resistance or OL on the multimeter.

2.3.2 Subsystem 2 - User Interface

The User Interface subsystem provides the graphical interface for the PTM Dome project, adapted from the previous semester's implementation using Python's tkinter library. Upon activation, the software automatically identifies available communication channels to locate the ATMega32U4 processor's specific vendor ID and establishes a serial connection.[1] The GUI window presents two primary operation modes:

- Automatic Imaging Mode: Pressing the "Start" button sends a signal to the microcontroller to initiate the pre-programmed imaging process, which activates all 32 LEDs in sequence and captures corresponding images. This allows users to efficiently capture a complete set of images with minimal interaction with the system.
- Manual Imaging Mode: Users can enable/disable specific LEDs and capture single images. This mode is primarily used for troubleshooting, testing, and situations where a singular well-lit picture of an artifact is wanted.[2]

The interface continuously displays the RTI device's connection status, ensuring users remain informed of the system's current state, and offers an intuitive layout that simplifies LED control for museum employees while preventing motion in the dome during operation. Communication between the UI subsystem and the microcontroller occurs via USB, utilizing the ATMega32U4's built-in USB controller. User commands for starting lighting sequences or toggling individual LEDs are transmitted from the UI to the microcontroller, which processes these commands to control the LEDs accordingly. The microcontroller sends real-time feedback to the UI, including connection status and current LED states which allows the interface to update dynamically.

This software-based control system provides flexibility for modifications if issues arise and enhances usability for museum staff through its adaptability. It also reduces potential points of failure in the PCB by eliminating physical buttons and their connectors that would otherwise be susceptible to wear and degradation. For this control implementation, the user interface transmits UART signals through an attached connector that interfaces between the user's computer and the PCB/microcontroller.

Requirement	Verification
The GUI supports both Automatic and Manual Imaging modes	Clicking each button triggers the corresponding function
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	UI correctly updates based on microcontroller feedback. Simulate communication failure and verify the correct error message appears
The system must not cause any unintended motion in the dome	Observe dome stability during image cycles
The user interface must be intuitive and require minimal training	An average person is able to learn how to use the interface within 10 minutes without assistance

2.3.3 Subsystem 3 - LED Lights and Dome

This subsystem consists of a dome fabricated by the machine shop with 32 integrated MR11 LEDs operating at a maximum power of 2.5 Watts apiece at 12V. It connects directly to Subsystem 1, which controls the power and lighting sequences. We will evaluate the wiring for compatibility with the LED controller board and verify its functionality to ensure that it can handle the required power draw. This subsystem is essential for the visual output of the PTM Dome, translating control signals from the LED drivers on the PCB into physical lighting effects.

Requirement	Verification
LEDs shall draw less than 300mA of current each.	Connect LED to DC Power supply and measure current draw at 12V DC.
LEDs shall be replaceable within the dome without tools.	Verify that LEDs can be replaced without tools.

2.3.4 Subsystem 4 - Longevity & Repairability

Longevity and Repairability is an incredibly important aspect of a design like this. Modern electronics tend to be designed with more of an emphasis on looks and manufacturing cost than longevity. This is not the goal here. The Spurlock Museum has indicated that they would like to use this system for many years to come. There are several components that go into meeting that goal. It starts with designing with the future in mind - all possible factors must be considered. What happens when a component fails? What happens when someone who was not involved in the design is tasked with repairing something? There are two ways to design for this. Components can be designed so that they have a smaller chance of failure, and they can be designed to be easily replaceable if they do fail.

One of the biggest obstacles to repairability in the past decade or so has been glue and other adhesives. Many electronics designs use adhesives to secure components because it is lightweight and strong - and the designers never expect the component to be replaced. Some adhesives are so strong that if they are removed, the component they are holding in place will not function properly afterwards. The design of this entire system is based around being able to replace every single component with basic hand tools. The PCB will be screwed into the enclosure, the wires will be screwed onto terminals, and components that might wear out (e.g. lightbulb sockets) are modular.

The second component to repairability is documentation. A device can be simple to repair, but damage or injury can be caused if documentation is not provided and the proper steps are not followed. This system will come with a set of manuals for both use and repair/troubleshooting. The user manual will cover all aspects of software and hardware use without disassembly of the system, and the repair manual will cover the assembly/disassembly of all components. Additionally, troubleshooting instructions will be provided for common issues, with diagrams and flowcharts. These manuals will be tested with people unfamiliar with the project, and revised based on their feedback. The end goal is that anyone should be able to use, troubleshoot, and repair the PTM dome.

Requirement	**Verification**
A user manual shall be provided which encompasses all aspects of normal device operation.	The user manual will be provided to a person who is unfamiliar with the project. They will be able to fully execute all instructions properly.
A troubleshooting & repair manual shall be provided which includes detailed instructions for troubleshooting common issues, and common repairs that will need to be performed.	The troubleshooting & repair manual will be provided to a person who is unfamiliar with the project. They will be able to fully execute all instructions properly.
Spare parts will be provided to ensure system longevity.	At least one spare of each replaceable component will be provided.
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.	The team shall verify that all components can be disassembled and reassembled without causing damage to anything.

2.3.5 Subsystem 5 - Control Enclosure

The control enclosure will house all essential components including the PCB, microcontroller and LED drivers, ensuring they are protected from environmental factors such as dust, moisture, and electrostatic discharge (ESD). This enclosure is essential to the overall design because it safeguards the internal hardware from physical damage and external interference, contributing to our design's high-level requirement of long-term stability and reliability. The enclosure will also include proper ventilation to allow for heat dissipation, ensuring internal temperatures remain below 120°F (322K) at all times. External connectors for power, camera control, and LEDs will be securely mounted with EMI shielding to prevent signal interference. The enclosure will interface directly with the LED Controller Board.

We plan to 3D print the enclosure in-house using ABS or PETg filament, chosen for its thermal resistance, durability, and ease of modification. This option allows for rapid prototyping and adjustments during the design phase. As a backup, the ECEB machine shop will be used to construct a custom enclosure from metal or durable plastic, ensuring precise cutouts for connectors, ventilation, and fastening points. This dual-plan approach ensures we have flexibility in fabrication while maintaining high standards for durability and protection.

Requirement	**Verification**
Control board enclosure provides adequate protection against physical damage and ESD for the control board.	Ensure that the enclosure has no way for users to inadvertently make contact with the PCB material, except for connectors.
Enclosure is able to be disassembled with a standard screwdriver.	Verify all connections are made with standard fasteners.
Components inside the enclosure can be replaced several times without damage to the enclosure	Ensure all standoffs are metal. Install/remove control board three times and ensure no wear and tear on the enclosure.

2.4 Hardware Design

Our PCB hardware design consists of _ different subsystems: (1) the power subsystem, (2) the microcontroller unit, (3) the LED controllers, (4) the shutter controller, (5) the USB controller.

For the power subsystem, we are using a DC jack rated at 24V and a maximum current of 5 Amps [4]. This is converted to 5V DC via a 1 Amp DC-DC step-down converter [5]. Both the input pin and output pins of this power supply are connected to capacitor banks to reduce noise at both the 24V input and 5V output. Specifically, the input voltage is connected to a capacitor bank with 0.1uF, 1uF, 10uF, and 22uF capacitors to reduce various frequencies of input noise, while the output power pin is connected to a capacitor bank with 10uF and 22uF capacitors, selected for bulk and to reduce noise from the internal switching regulators.

For the microcontroller unit, we are using the ATMega32U4, a low-power, RISC-based, 8-bit controller. It consumes a maximum of 27mA of power at an operating voltage of 5V [6], which it receives from the 5V DC-DC converter. Outputs on PORTB are reserved for SPI control of the LED drivers (PB1-PB3), shutter control (PB4 and PB7), and PWM control of two of the LED drivers (PB5 and PB6). Outputs on PORTC act as additional PWM signals for two of the LED drivers (PC6 and PC7). Finally, outputs on PORTF act as the SPI chip selector for each of the four LED drivers (PF4-PF7). The MCU also has connections to a reset pin (active low RESET) and several test points. [6]

The LED controllers consist of four separate LED controller units. For the LED drivers, we used highly reliable 8-pin output relay drivers typically used for automotive applications. They are rated at a continuous load current of 400mA per pin at 5V input, well above the maximum 208mA current drawn by the LEDs [7]. Each of these LED drivers has its own PWM signal and SPI chip select signal from the microcontroller, with a shared SPI bus selecting which individual LED to drive. Because we have four drivers, we can drive up to four LEDs at once which is enough to perform traditional photography with the dome, and the PWM input allows for individual dimming of lights. Each of the outputs to these drivers was connected to both the 16-pin MOLEX headers [8] and to a shared ground via a normalizing 4.7nF capacitor. The shared ground was connected to the ground plane via a set of eight zero-Ohm resistors, to prevent the noisy ground of the drivers from impacting other components. The other 8 pins of the MOLEX connectors were connected directly to the 24V source, with the LEDs bridging the source voltage and the driver outputs.

For the shutter controller, we used one phototransistor optoisolator each for the shutter and focus signal from the microcontroller unit [9]. The outputs of this optoisolator were connected to test points and to a 3.5mm jack [10]. This 3.5mm jack was connected to the Canon EOS-1D camera through a 3.5mm to N3 cable [11, 12], to enable remote control of the shutter and focus.

Finally, the USB controller consists of a standard USB-C jack [13], with the voltage and ground driven by the computer connected to the PCB, and D+ and D- connected to the microcontroller for programming. The D+ and D- inputs were isolated from the board via 22 Ohm resistors, and connected to ground via automotive varistors for additional electrostatic discharge protection [14].

2.5 Software Design

2.5.1 Microcontroller State Management

The decision-making enabled by the ATMega32U4 microcontroller is a crucial part of the project. The microcontroller responds to user commands and executes the corresponding illumination sequence of the 32 LEDs. The algorithm implemented for the microcontroller receives command from the GUI and determines the appropriate operational state for the dome. These states form the foundation of our control logic and ensure reliable and predictable operation of the system. The possible states of operation are:

- *START* - The microcontroller is at standby and it waits for user directive without transmitting any activation signals to the LEDs. The dome system is inactive until the user selects a mode through the GUI. This is both the initial state after a power-up and the return state after a complete image cycle.
- *AUTO_START* - On receiving the “Automatic Imaging” command from the GUI, the microcontroller activates the 32 LEDs in sequence, precisely controlling the timing between LED illumination and shutter activation. After successfully capturing images 32 times, the system automatically transitions to the *AUTO_COMPLETE* state
- *AUTO_COMPLETE* - The system uses the GUI to communicate the successful completion of an automatic imaging sequence to the user. “Imaging Complete” is then displayed to the user and the system returns to *START*.

- *MANUAL_START* - In response to user selections through the GUI, the microcontroller activates a specific LED. The system remains here until directed to capture another image or return to standby
- *MANUAL_COMPLETE* - Provides feedback to the user by displaying “LED Active” when an LED is powered on or “Imaging Complete” following individual image capture. The system then returns to either START or *MANUAL_START* depending on user input
- *ERROR* - When something unexpected happens, all imaging is halted and the LEDs are deactivated to prevent hardware components from getting destroyed. Simultaneously, an error notification is sent to the GUI which enables the user to identify and address the cause of the error

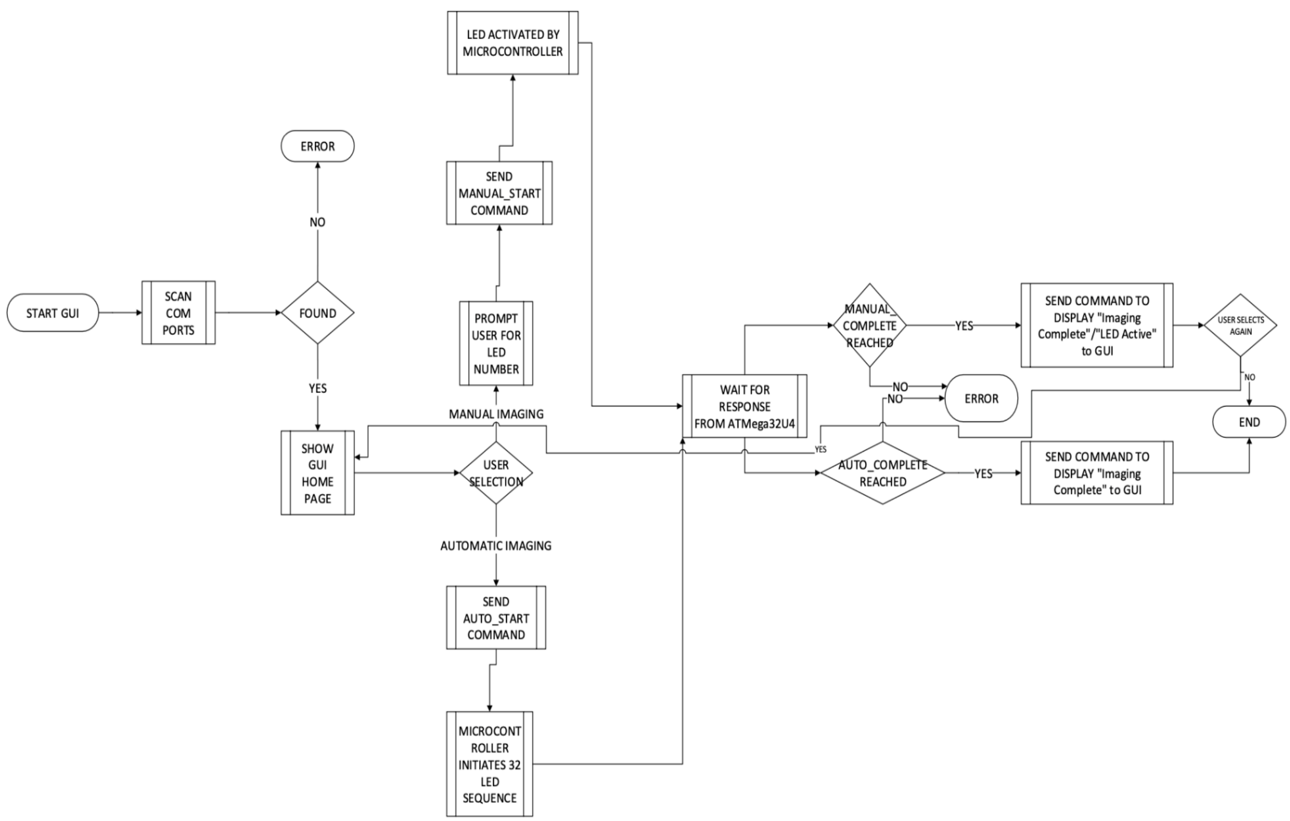


Figure 3, Flowchart of the software component

2.5.2 Communication Protocol Implementation

PySerial is used to establish reliable communication between the Python based GUI and the microcontroller through a USB-A connection. This communication channel links the user input and system response. When the program is launched, the software automatically scans for available COM ports to identify the ATMega32U4 microconotroller's unique vendor ID. This eliminates the need for manual port configuration, enhancing the system's user friendliness. The Python program transmits serial data in the form of command strings over the USB connection which is then received by the ATMega32U4's UART interface. These commands encode user inputs. The microcontroller processes these commands and responds to the GUI with appropriate status updates or error codes, maintaining a continuous feedback loop.

2.6 Commercial Component Selection

The majority of our components were generic surface-mount capacitors and resistors, so we will describe only the unique component choices here. The microcontroller we are using is the ATMega32U4, which we selected for its low power consumption (<30mA) and Arduino compatibility [6]. The LED drivers are TLE-8108-EM 8-pin relay drivers from Infineon. These drivers are designed for automotive drivetrain applications with several built in protections including overcurrent protection and undervoltage lockout, which is important for our key component of reliability [7]. They are also designed for use with PWM inputs, which allows us to control the dimming of LEDs for the manual (photography) operation of the dome [7]. We chose the LMZM23601 power supply to provide far more than enough power for each of the 5V ICs, see the Tolerance section for more information. This power supply is also highly reliable and efficient [7], and cost is not a major consideration for this project since we are aiming for reliability. Similarly, the optoisolators and ESD suppressors were chosen for their long-term reliability, as they are industry-standard for telephone line and automotive use, respectively [9, 14] The 430451601 MOLEX connectors for the LEDs were also chosen for their reliability and ease of use; the through-hole locking mechanism makes replacing LEDs much simpler for an end user [13].

Index	Manufacturer Part Number	Description	Quantity	Unit Price	Extended Price
1	0430451601	CONN HEADER R/A 16POS 3MM	4	$3.87	$15.48
2	TMK212BJ225KG-T	CAP CER 2.2UF 25V X5R 0805	4	$0.11	$0.45
3	C0805C472K1GECTU	CAP CER 0805 4.7NF 100V C0G	32	$0.08	$2.62
4	C0805C220J5GACTU	CAP CER 22PF 50V C0G/NP0 0805	4	$0.05	$0.18
5	CL32A106KAULNNE	CAP CER 10UF 25V X5R 1210	3	$0.17	$0.52
6	CL32A226MOJNNNE	CAP CER 22UF 16V X5R 1210	2	$0.21	$0.41
7	150080SS75000	LED RED CLEAR 0805 SMD	2	$0.17	$0.34
8	TS4148 RAG	DIODE STANDARD 75V 150MA 1206	1	$0.05	$0.05
9	4N26-X009T	OPTOISO 5KV TRANS W/BASE 6SMD	2	$0.53	$1.06
10	2012670005	CONN RCP USB3.1 TYPEC 24P SMD RA	1	$2.55	$2.55
11	PJ-018H-SMT-TR	CONN PWR JACK 1.7X4MM SOLDER	1	$0.86	$0.86
12	SJ2-3574A-SMT-TR	AUDIO JACK, 3.5 MM, RT, 4 CONDUC	1	$0.87	$0.87
13	RC0805FR-07220RL	RES 220 OHM 1% 1/8W 0805	2	$0.01	$0.02
14	RMCS1210ZT0R00	RES 0 OHM JUMPER 1/3W 1210	8	$0.10	$0.78

15	CG0603MLC-05E	VARISTOR 0603	2	$0.31	$0.61
16	FSM2JSMAA	SWITCH TACTILE SPST-NO 0.05A 24V	1	$0.20	$0.20
17	5019	PC TEST POINT MINIATURE	10	$0.27	$2.67
18	TLE8108EMXUMA1	IC PWR DRIVER N-CHAN 1:2 24SSOP	4	$3.64	$14.56
19	LMZM23601V5SILR	DC DC CONVERTER 5V	1	$5.17	$5.17
20	ABM7-16.000MHZ-D2Y-T	CRYSTAL 16.0000MHZ 18PF SMD	1	$0.66	$0.66
21	RMCF0805ZT0R00	0 Ohms Jumper Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	2	E-Shop	$0.00
22	RMCF0805JT1K00	1 kOhms ±5% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	10	E-Shop	$0.00
23	RMCF0805JG10K0	10 kOhms ±5% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	6	E-Shop	$0.00
24	CL21F104ZAANNNC	0.1 µF -20%, +80% 25V Ceramic Capacitor Y5V (F) 0805 (2012 Metric)	12	E-Shop	$0.00
25	CL21B105KBFNNNG	1 µF ±10% 50V Ceramic Capacitor X7R 0805 (2012 Metric)	13	E-Shop	$0.00
26	ATMEGA32U4-AUR	AVR AVR® ATmega Microcontroller IC 8-Bit 16MHz 32KB (16K x 16) FLASH 44-TQFP (10x10)	1	E-Shop	$0.00

27	61200621621	Connector Header Through Hole 6 position 0.100" (2.54mm)	1	E-Shop	$0.00
28	302-S101	Connector Header Through Hole 10 position 0.100" (2.54mm)	1	E-Shop	$0.00
29	UUD1E330MCL1GS	CAP ALUM 33UF 20% 25V SMD	3	$0.31	$0.93
30		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
31		Bi-pin Socket MR11	32	$0.80	$25.60
		MR11 LED Light Bulb	32	$3.00	$96.00
				Total	$184.44

Table 1: Bill of Materials, including cost

2.7 Tolerance Analysis

As opposed to the previous group, which used their DC-DC power supply for nearly every component (other than the LEDs), there are multiple lines of power for our PCB. One line of power is the direct 12V normalized line from the power jack, which can supply up to 5 Amps of current or 60 Watts [4]. For our system, the 12V normalized line powers the LEDs. Considering that our new system can turn on a maximum of four bulbs at once (one for each of the LED drivers), the maximum wattage for the LEDs is 10W which is well within tolerance for this line. The DC-DC step-down converter from 12V to 5V provides a maximum of 1 Amp current, or 5 Watts power, with a 0.01% tolerance within operating range of 6-36 Volts [5]. This provides power for the four LED drivers and the ATMega32-U4 microcontroller. The LED drivers each consume a maximum 6mA total current including leakage [7], for a total 24mA total current. On the other hand, the microcontroller consumes a maximum 28mA total current including leakage, at maximum operating frequency of 16MHz and operating voltage of 5V [6]. Total power on the 5V line is no more than 52mA, then, well within tolerance of 1 Amp. The last power line is from the USB connector, which only feeds into the microcontroller as an internal regulator. The ATMega32 takes an absolute maximum of 80mA of current through this regulator pin (in extreme cases), with any USB-C controller providing a bare minimum of 1 Amp of current at 5V [15], well above the requirements for the microcontroller.

For the most part, tolerance of response times for the LEDs and the camera shutter will be dependent on the ICs used for the LED drivers and the optoisolators on the 3.5mm jack, in addition to any processing delay on the part of the microcontroller. Time is not a major constraint in regular PTM operation of the dome, however it is important that LEDs are responsive to control signals for smooth user operation of the device. Our requirement for 1ms tolerance for toggling LEDs and 50ms tolerance on the shutter are fairly arbitrary, given the ICs have hold and delay times in the microsecond to nanosecond range. The primary source of delay in the circuit would be processing times for commands on the microcontroller, which will be dependent on our software implementation of the control system. Given that 1ms switching delay (1000Hz) is within the limits of perceptibility for the human eye, we felt it was a good standard for evaluating the perception of smooth LED toggling (without lag). Tolerance for the shutter is less important since only a few pictures can be taken per second regardless.

2.8 Cost Analysis

For parts cost breakdown, see the Bill of Materials in Section 2.6.

Labor costs are calculated with the following formula:

$50/hr * 12 hours/week * 3 partners * 16 weeks = $28,800

Total cost: $28,800 labor + $184.44 parts = **$28,984.44**

2.9 Schedule

Week	**Task**	**Partners**
1	Project Selection	All
2	RFA	All
3	RFA/Project Approval	All
4	Meet with Spurlock to discuss requirements	All
4	Project Proposal	All
5	Proposal Review	All
5	Begin User/Repair Manual Design	Sam
5	Dome Rewiring	Sam
6	Socket Soldering	Priya/Nick
6	Design Document	All
7	Order Components	Sam
7	Initial Software Requirements Identification	Priya/Nick
7	Continue Dome Wiring	All

7	Breadboard Testing	All
8	PCB Assembly	Sam
8	Initial Software Testing	Priya/Nick
8	Continue software development	Priya/Nick
9	Continue Manual Drafts	Sam
9	Final Assembly & design verification	All
10	Final Assembly & design verification	All
11	Contingency Week	All

2.10 Risk Analysis

The PTM Dome system relies on precise LED operation and stable microcontroller operation which makes power instability, communication failures, and overheating key risks. Voltage fluctuations could disrupt LED performance or reset the microcontroller, while UART communication failures may prevent the system from responding to user input. prolonged LED operation could also cause overheating, potentially shortening the lifespan of components. Physical wear on connectors and cables, as well as environmental factors like dust or accidental impacts, could further degrade system reliability over time.

To mitigate these risks, we will use capacitors to prevent power fluctuations, while implementing error detection in the user interface to catch failures early. Heat sinks or cooling periods will reduce overheating risks, and using high-quality connectors will prevent wear-related failures. To ensure ease of use, the GUI will be designed with "buttons" and descriptions to minimize user errors. A protective enclosure will help shield components from environmental damage, ensuring long-term reliability.

Ethics and Safety

- **Public Safety and Welfare (IEEE Code of Ethics #1 & #9):** We will ensure that our system is electrically safe by properly insulating the 12V LED circuits and incorporating overcurrent protection to prevent short circuits or overheating. We will also keep sensitive electronics in an ESD-safe enclosure to prevent static discharge, following IEEE safety standards for electrical design. We will also ensure that the enclosure for the electronics is protected from dust and other environmental hazards.
  Additionally, we will ensure that light pulses used for artifact scanning remain below 100 lux for highly sensitive items (e.g., textiles, paper, photographs) and below 200 lux for less sensitive items (e.g., wood, undyed leather). The power supplied to LEDs will remain within rated specifications to prevent damage to artifacts and system components.
  We will provide an instruction manual to guide users in safe operation, troubleshooting, and equipment replacement to avoid electrical injury.[3]
- **Honesty and Transparency (IEEE Code of Ethics, #3 & #7):** We will clearly document our system, ensuring museum staff can use and maintain it without risk of misuse.[3]
- **Avoiding Harm and Misuse (IEEE Code of Ethics, #5):** The system will be designed to prevent accidental misfiring of the camera by ensuring the trigger signal is precisely timed. We aim to comply with FCC regulations on electromagnetic interference and UL safety standards for electrical components.[3]

3. Citations

- [1] S. Leigh, A. Meissner, and P. Xie-O'Malley, ECE 445 Design Document Fall 2024.
- [2] A. Calmas, H. Doromal, and J. Ducham, ECE 445 Reflectance Transformation Imaging Dome
- [3] IEEE Computer Society, "Code of Ethics | IEEE Computer Society," *Computer.org*, 2017. https://www.computer.org/education/code-of-ethics
- [4] Same Sky Electronics, "DC Power Jack Connector," PJ-018H-SMT-TR datasheet, Sept. 2024 https://www.sameskydevices.com/product/resource/pj-018h-smt-tr.pdf
- [5] Texas Instruments, "36-V, 1-A Step-Down DC-DC Power Module," LMZM23601 datasheet, Dec. 2017 [Revised Mar. 2023] https://www.ti.com/product/LMZM23601.
- [6] Microchip, "ATmega32U4," ATmega32U4 datasheet, 2016 https://www.microchip.com/en-us/product/ATmega32U4.
- [7] Infineon, "TLE8108EM", TLE8108EM datasheet, Mar. 2011 https://www.infineon.com/cms/en/product/power/smart-power-switches/multichannel-spi-switches-controller/flex-multichannel-spi-low-side-power-switch/tle8108em/.
- [8] MOLEX, "0430451601", 0430451601 datasheet, Nov. 2024 https://www.molex.com/en-us/products/part-detail/430451601.
- [9] Vishay Electronics, "Optocoupler, Phototransistor Output, with Base Connection", 4N26-X009T datasheet, Jan. 2012 https://www.vishay.com/docs/81864/4n25x000.pdf.
- [10] Same Sky Electronics, "4 conductors, 3.5mm, SMT Audio Jack," SJ2-3574A-SMT-TR datasheet, Sept. 2024 https://www.sameskydevices.com/product/resource/sj2-3574a-smt-tr.pdf .
- [11] *Canon EOS-1D X User Manual*, Canon, Tokyo, Japan. [Online] https://www.csai.canon.com/support/p/eos-1d-x.

- [12] “Canon N3 Connector Pinout and Wiring,” *Martybugs.net*, Nov. 2008. https://martybugs.net/blog/blog.cgi/gear/CanonN3Connector.html.
- [13] MOLEX, “105450-0101”, 1054500101 drawing, Mar. 2019 https://www.molex.com/en-us/products/part-detail/1054500101.
- [14] Bourns, “CG0603MLC-05E,” CG0603MLC-05E datasheet, Mar. 2015 https://www.bourns.com/products/circuit-protection/chipguard-esd-suppressors-aec-q200-compliant/product/CG0603MLC-05E/%20CG0603MLC-12E%20Automotive.
- [15] USB-IF, “USB Power Delivery ,” www.usb.org, Nov. 09, 2024. https://www.usb.org/document-library/usb-power-delivery.