UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Polynomial Texture Mapping Dome Restoration

Team 22
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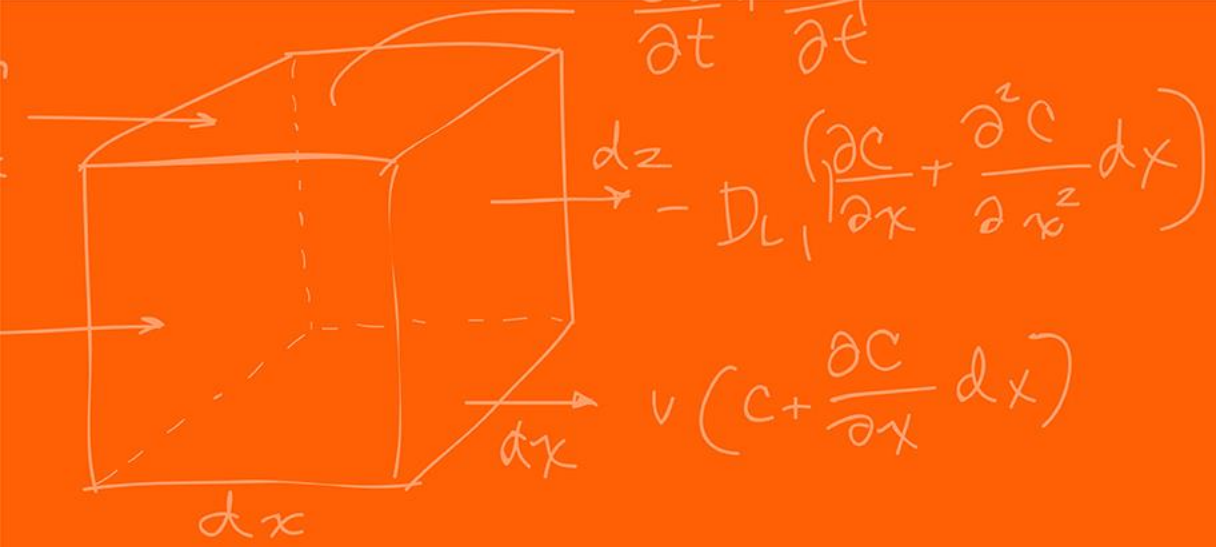
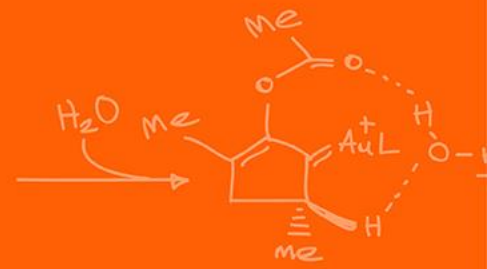
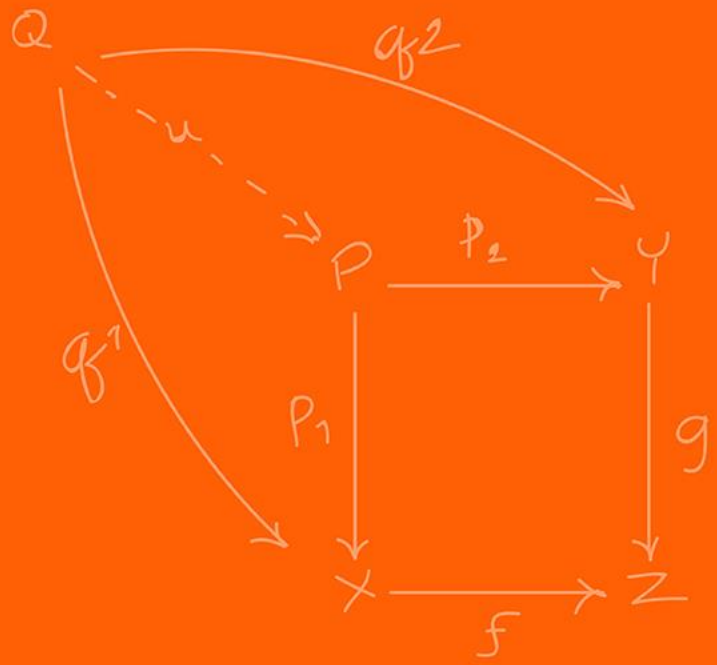




Overview



Introduction and Context

- The Spurlock Museum uses a Polynomial Texture Mapping (PTM) dome to digitally preserve artifacts

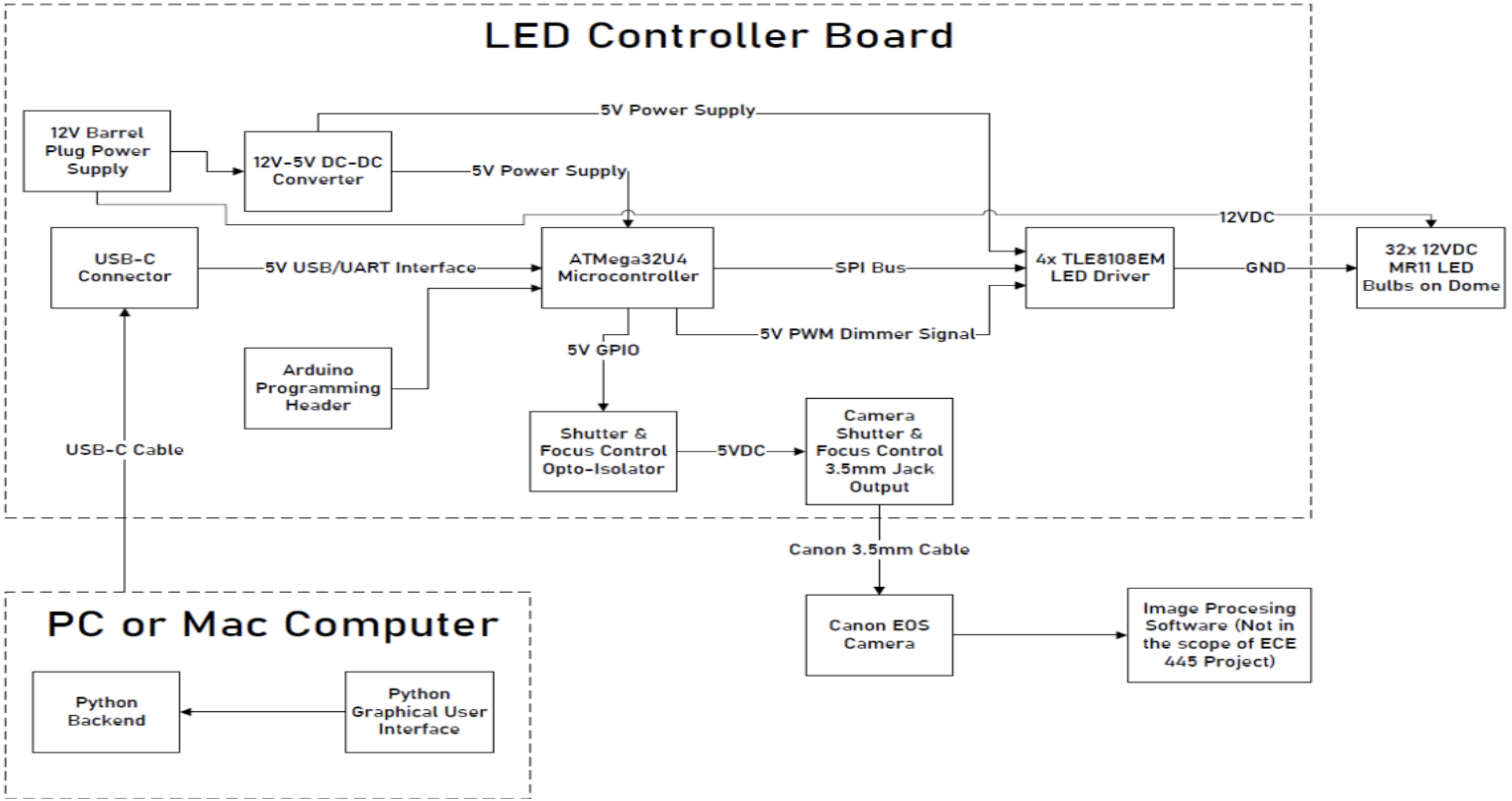
- The dome captures **32 images** of an artifact, each illuminated from a different direction. These images are then processed to reveal surface textures and details that are difficult to see under normal lighting

- **Automatic mode**: all 32 LEDs are triggered in sequence while the camera captures each image
- **Manual mode**: individual LEDs can be toggled for focused inspection or testing

- The goal of this project was to **restore full functionality** to the dome using a new control system, stable hardware, and a user-friendly interface

- We also focused on **reliability, ease of repair, and long-term usability** for museum staff

Block Diagram



High-Level Requirements

Precision LED Sequencing and Control

- Must toggle all 32 LEDs both manually and automatically
- LED switching accuracy: **within 1ms**
- LEDs must **remain stable** with no flickering or crosstalk

Accurate Camera Shutter Synchronization

- Camera must be triggered within **50ms** of LED activation
- Uses a 3.5mm opto-isolated trigger line to **avoid noise and misfires**

Long-Term Reliability and Stability

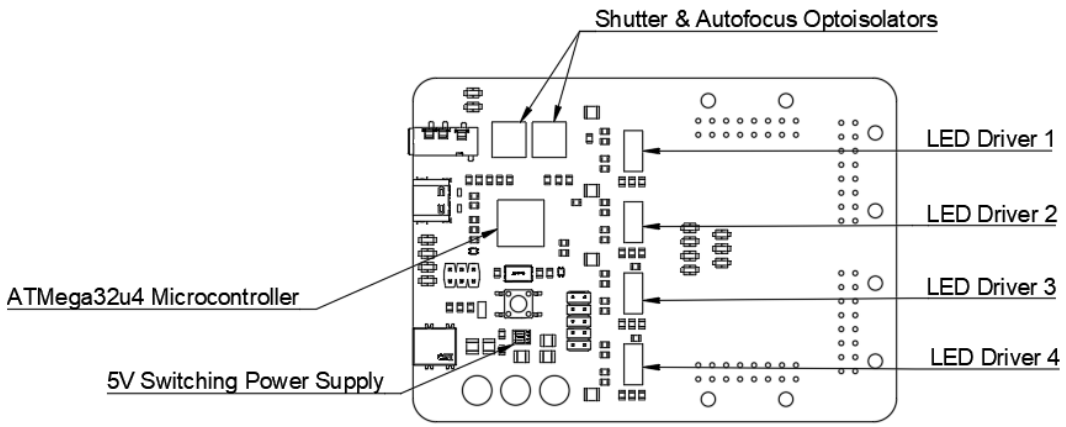
- System must withstand **multiple** full imaging cycles without failure
- Must operate across **multiple operating systems** with minimal maintenance
- Prevent overheating of PCB and ensure EMI protection

Major Design Changes Implemented

Original Design	Final Design
PCB had a floating optoisolator pin, causing unreliable shutter signals	Reprinted PCB with added pull-down resistor for stable camera triggering
LED modules with complex internal circuitry, not compatible with our drivers	Replaced with basic "dumb" LEDs
Using 32 separate lines for each individual LED, connected via pull-up drivers	Using pull-down drivers to reduce strain on the PCB
Control Enclosure printed with ESD safe PETg filament	Control enclosure printed with regular PLA filament + ESD safe coating

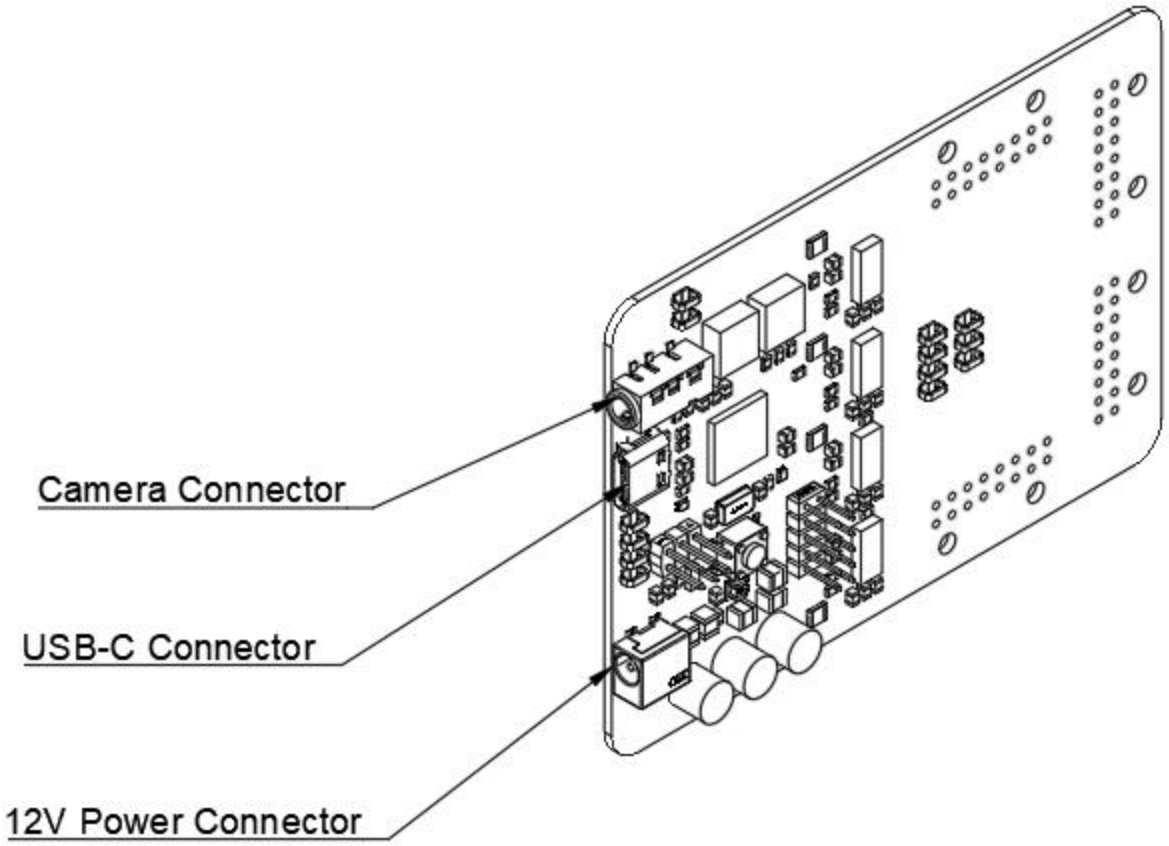
Printed Circuit Board Design

Printed Circuit Board Design- Components

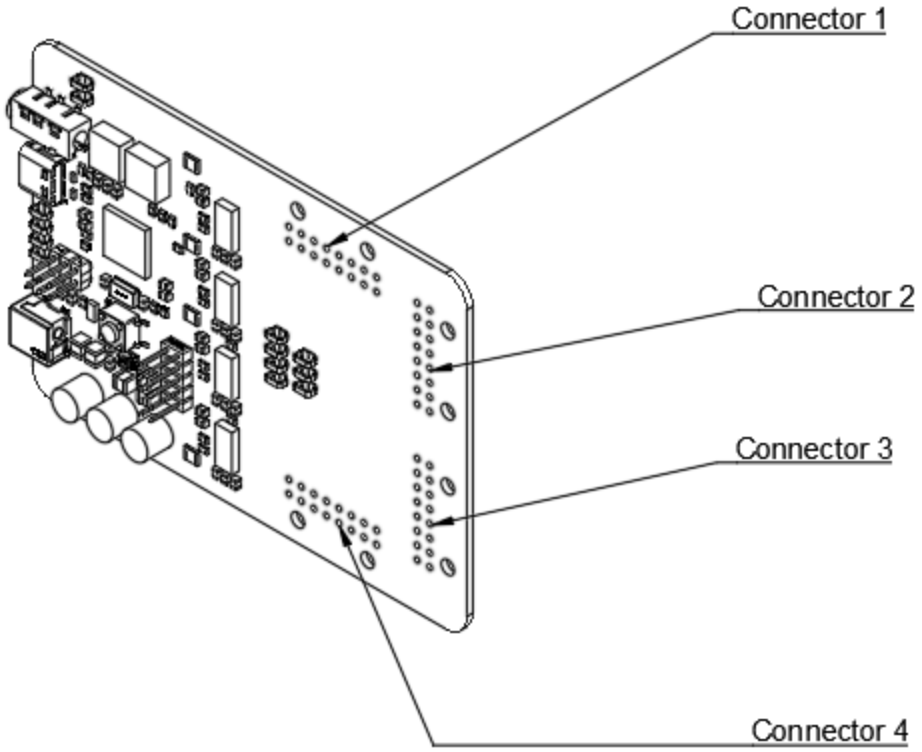


- ATMega32u4 Microcontroller
  - Built-in USB Controller
  - Arduino Compatibility
- NCV7240 Low-Side Drivers
  - High Current Limit – Many LEDs at the same time
  - SPI Control & Diagnostic Info
- Opto-Isolators for Camera Control
  - Protects camera & PCB by electrically isolating them from each other

Printed Circuit Board Design- Interface Connections

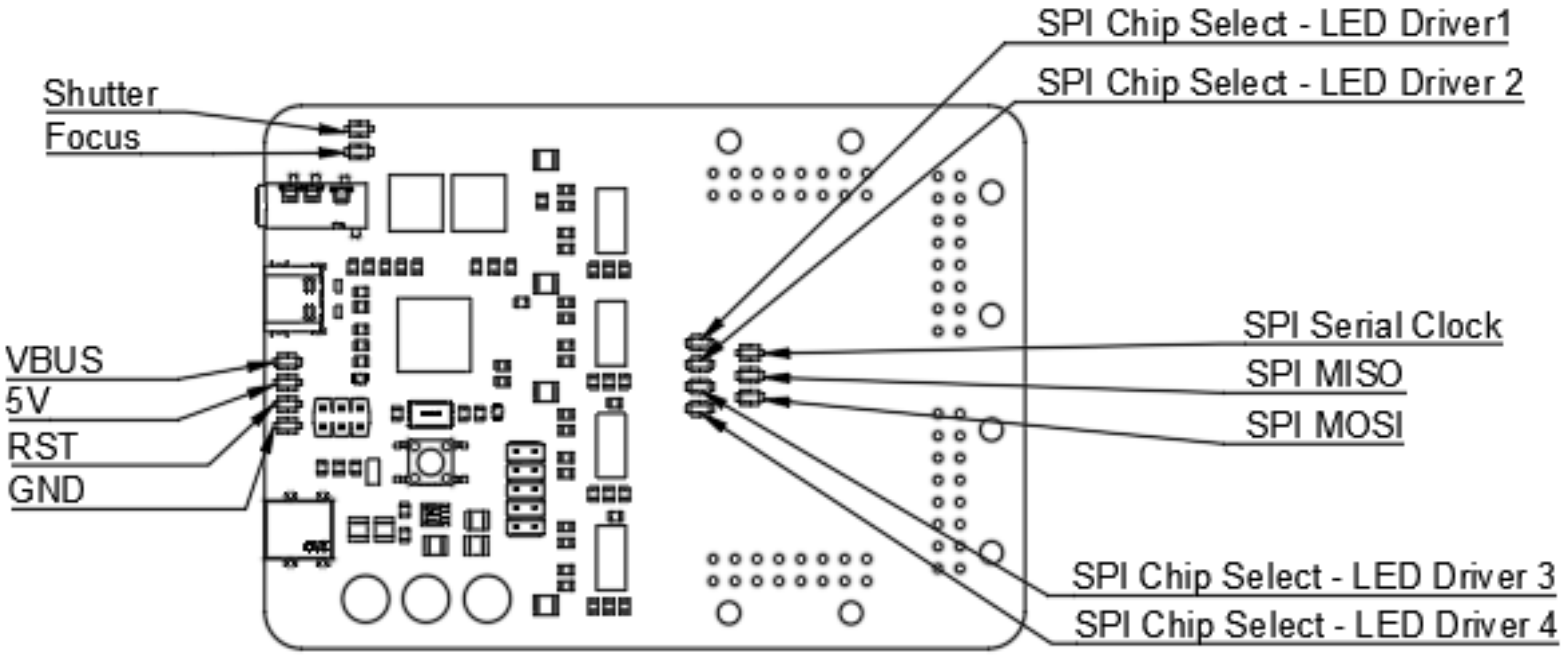


Printed Circuit Board Design- LED Connections



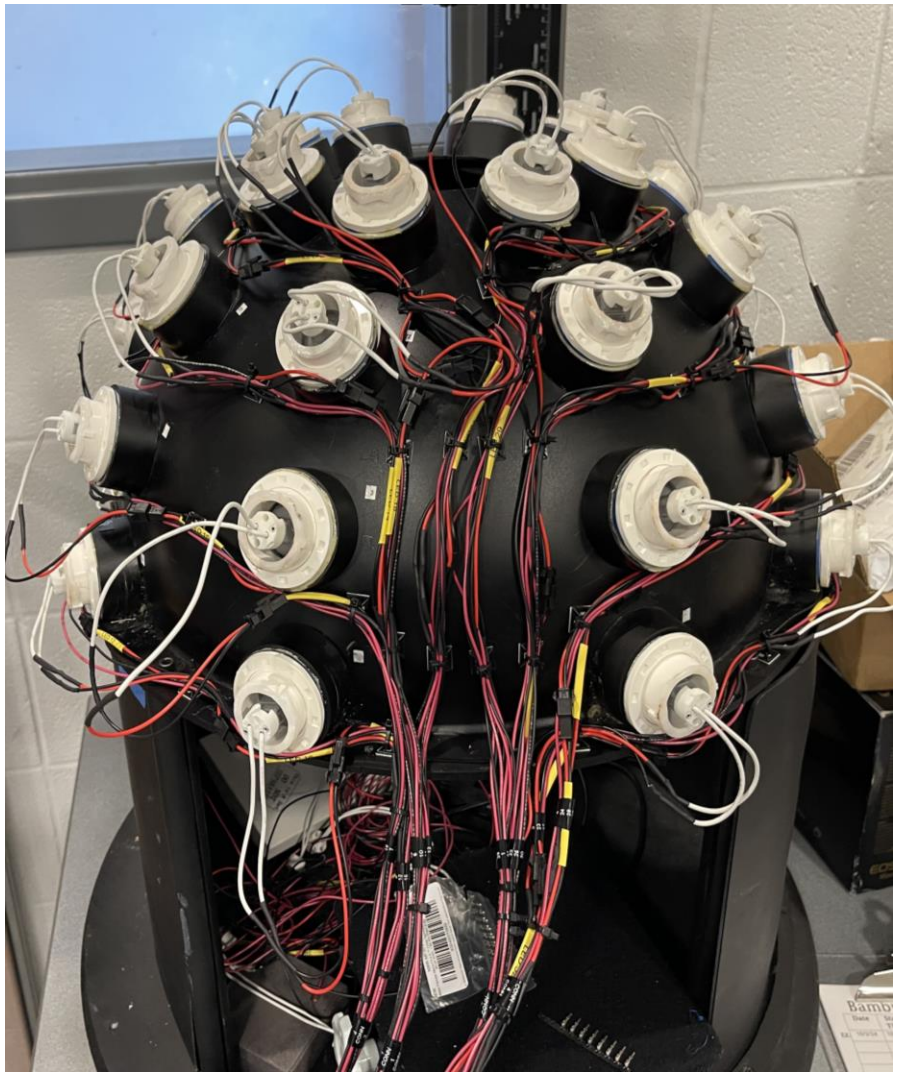
- 4 16-Pin Molex Micro-Fit 3.0 Connectors
  - 8 LEDs Per Connector
  - 1 Connector per driver
- Robust design allows for solid electrical connections but also allows for easy disconnection if repairs are necessary
- Widely-available connector means replacement is simple

Printed Circuit Board Design- Test Points

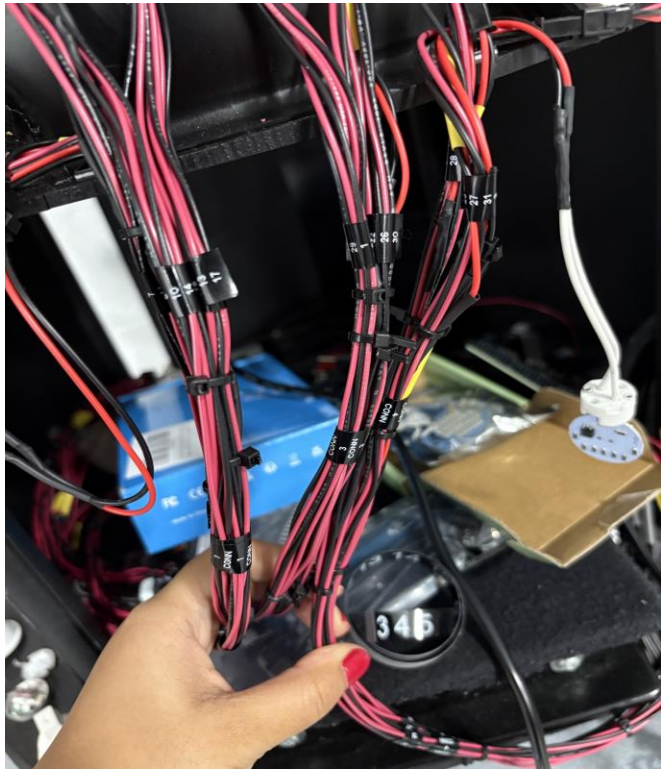


PTM Dome & LEDs

PTM Dome and LEDs - Wiring

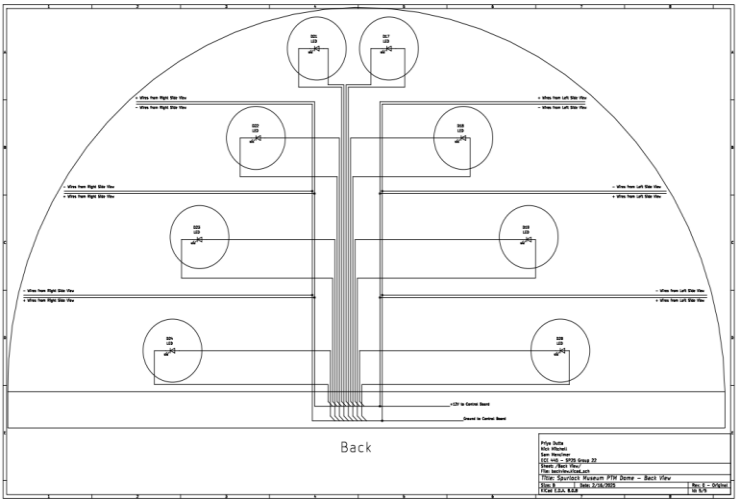


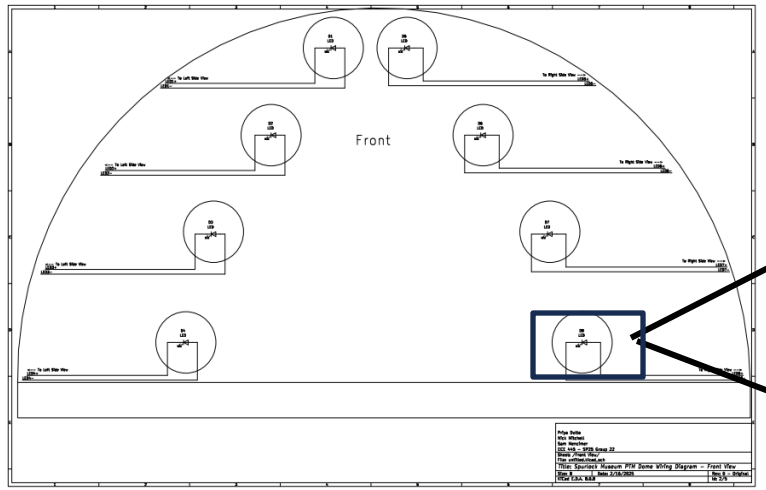
- Dome made from durable black plastic by the Machine Shop
- Contains 32 LEDs arranged hemispherically around the dome
- LEDs grouped using 4 connectors (8 per group) and each connector is routed to a dedicated LED driver on the PCB
- Original LEDs were incompatible with our PCB so we made custom LED units

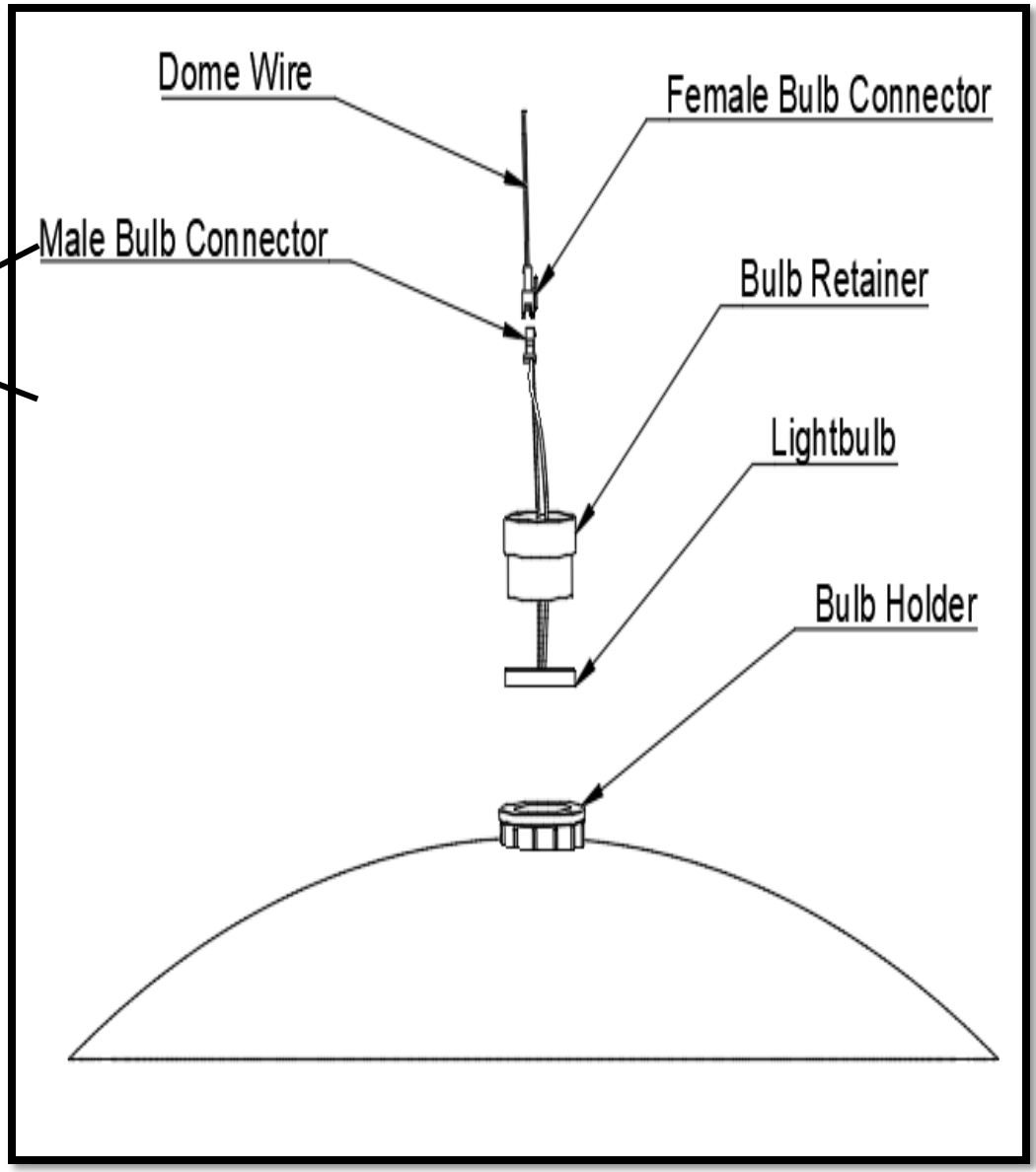


There are 4 connector units each containing 4x2 = 8 LED wires.

PTM Dome and LEDs - LED Mount

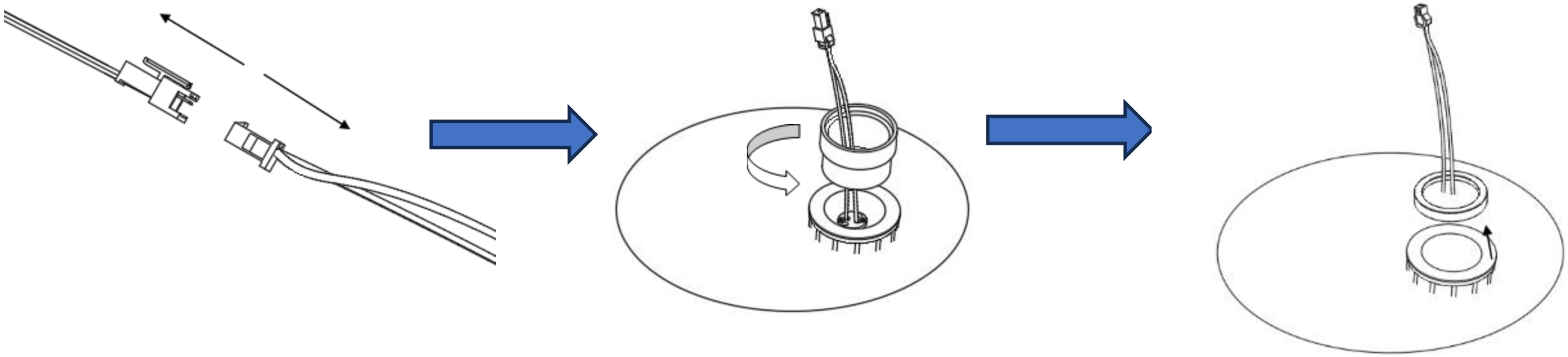






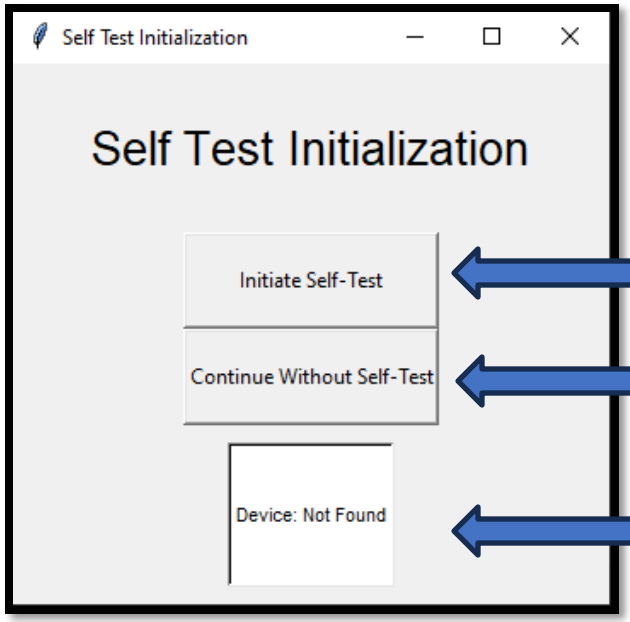
- Each LED is installed in a modular mount with a custom 3D printed retainer to ensure a secure fit into the dome
- LEDs are easy to install, remove, and replace and no adhesives or soldering is required at the dome
- The image on the right shows the structure of a LED unit

PTM Dome and LEDs- LED Replacement



User Interface & Software

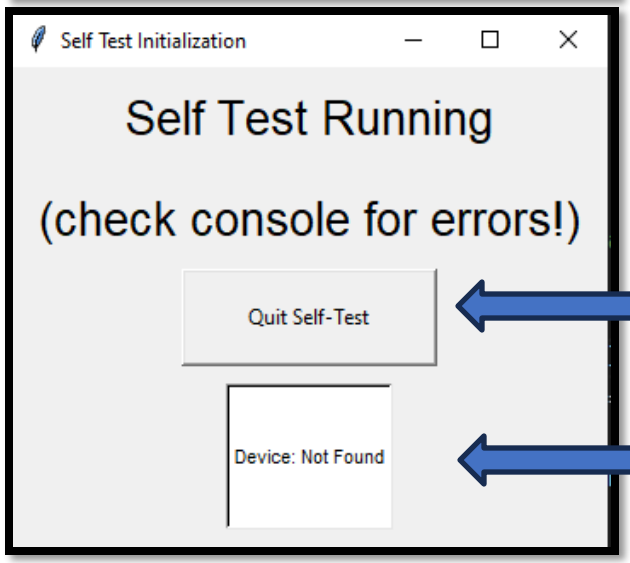
GUI Self-Test



Initiates the Self-Test, and pulls up the Self Test Running window

Skips the Self-Test, and pulls up the Home window for the controller

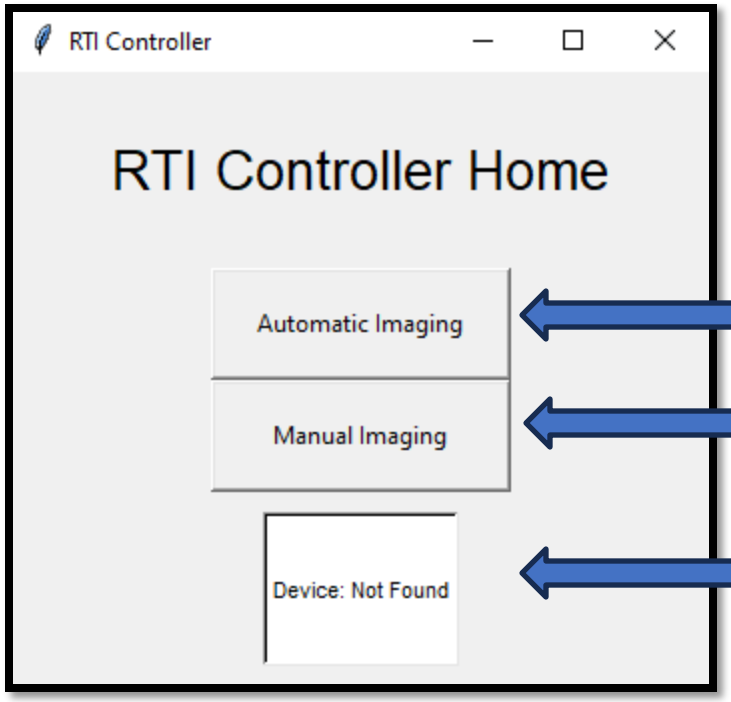
Indicates the VID and PID of the connected device



Resets all LEDs and pulls up the Home window for the controller

Indicates the VID and PID of the connected device

GUI Home

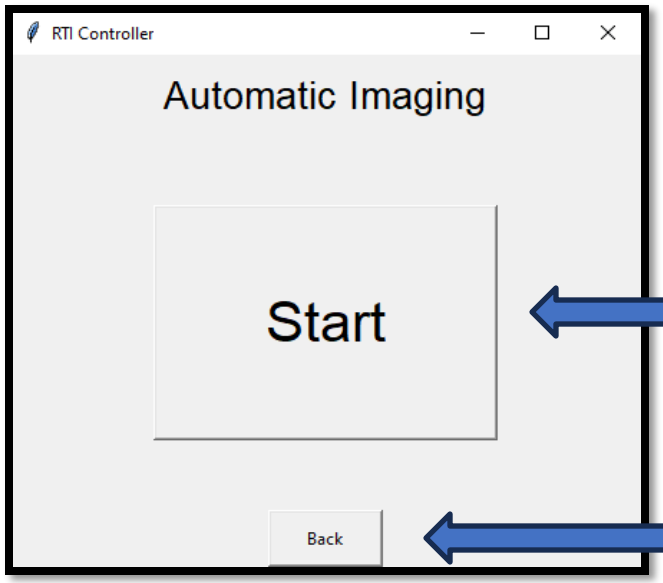


Opens the Automatic imaging panel

Opens the Manual imaging panel

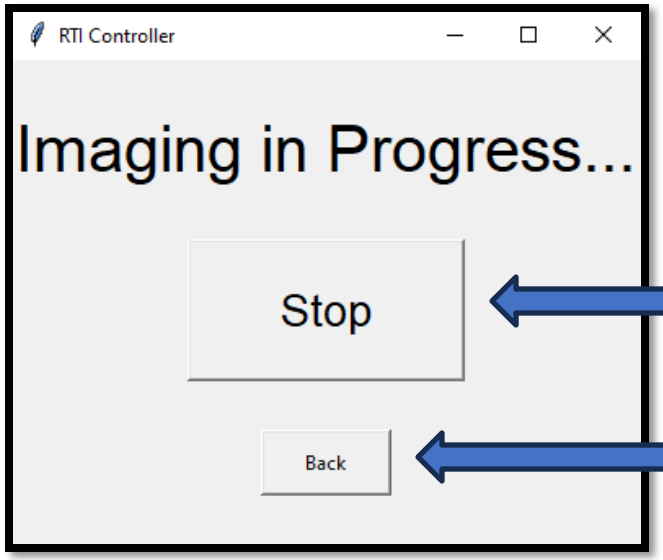
Indicates the VID and PID of the connected device

GUI Automatic



Start imaging

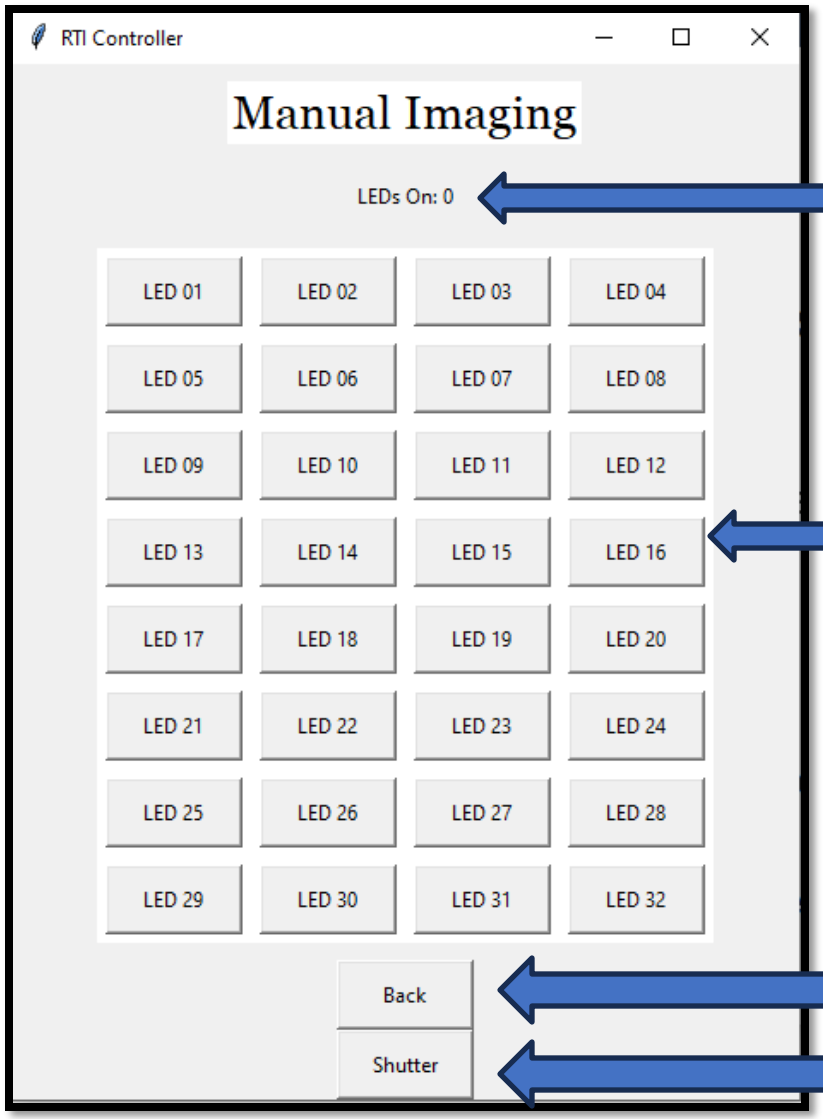
Reset LEDs and return to Home



Stop imaging (Resets LEDs)

Reset LEDs and return to Home

GUI Manual



Number of LEDs on

Toggle for each individual LED

Reset LEDs and return to Home

Activate camera shutter

Flowchart for the Python GUI

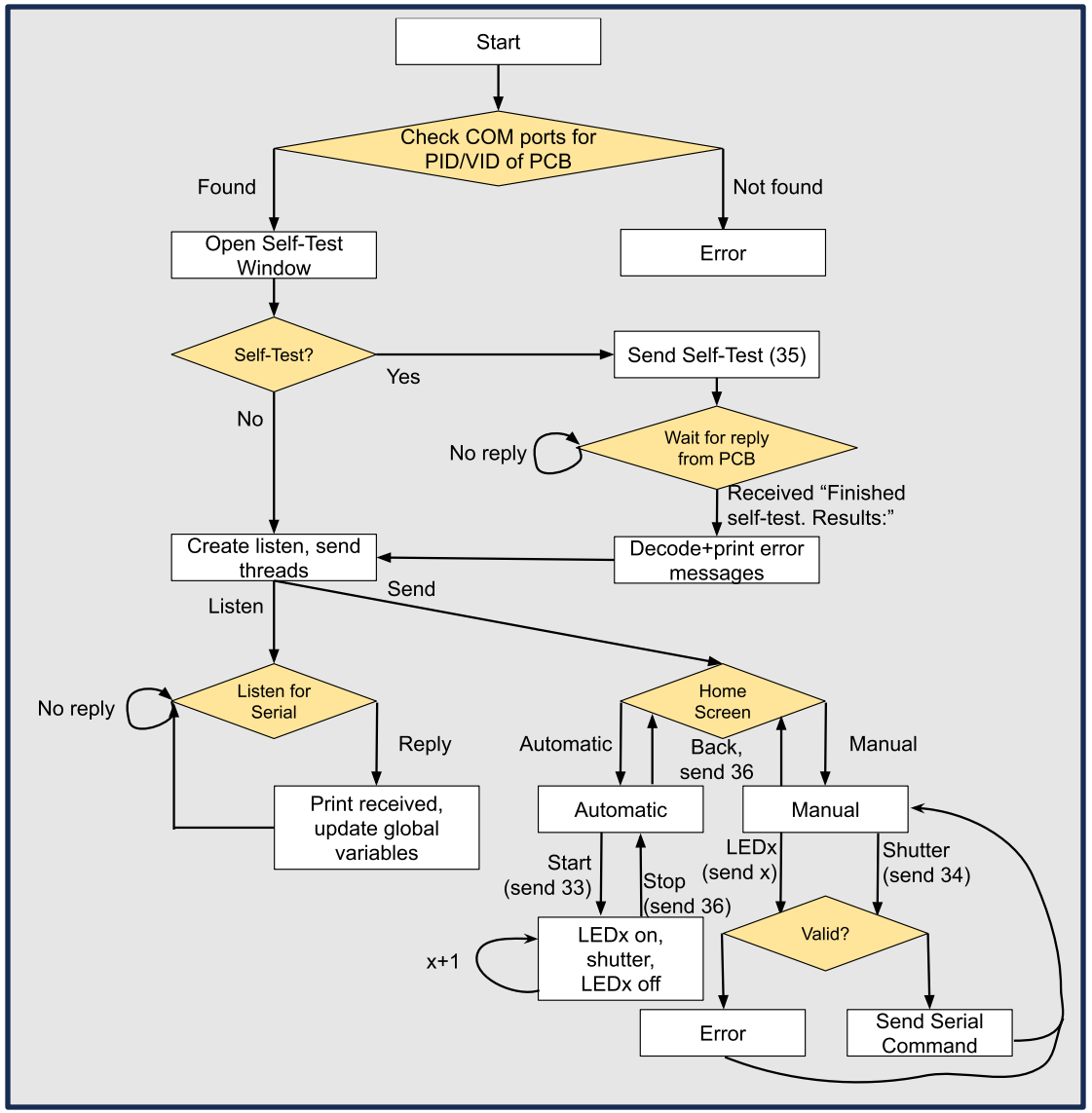
Right side: flowchart for the Python GUI

Uses standard **tkinter** for GUI, **serial** for connection to PCB, **threading** for multithreading, and **sys** for error messages

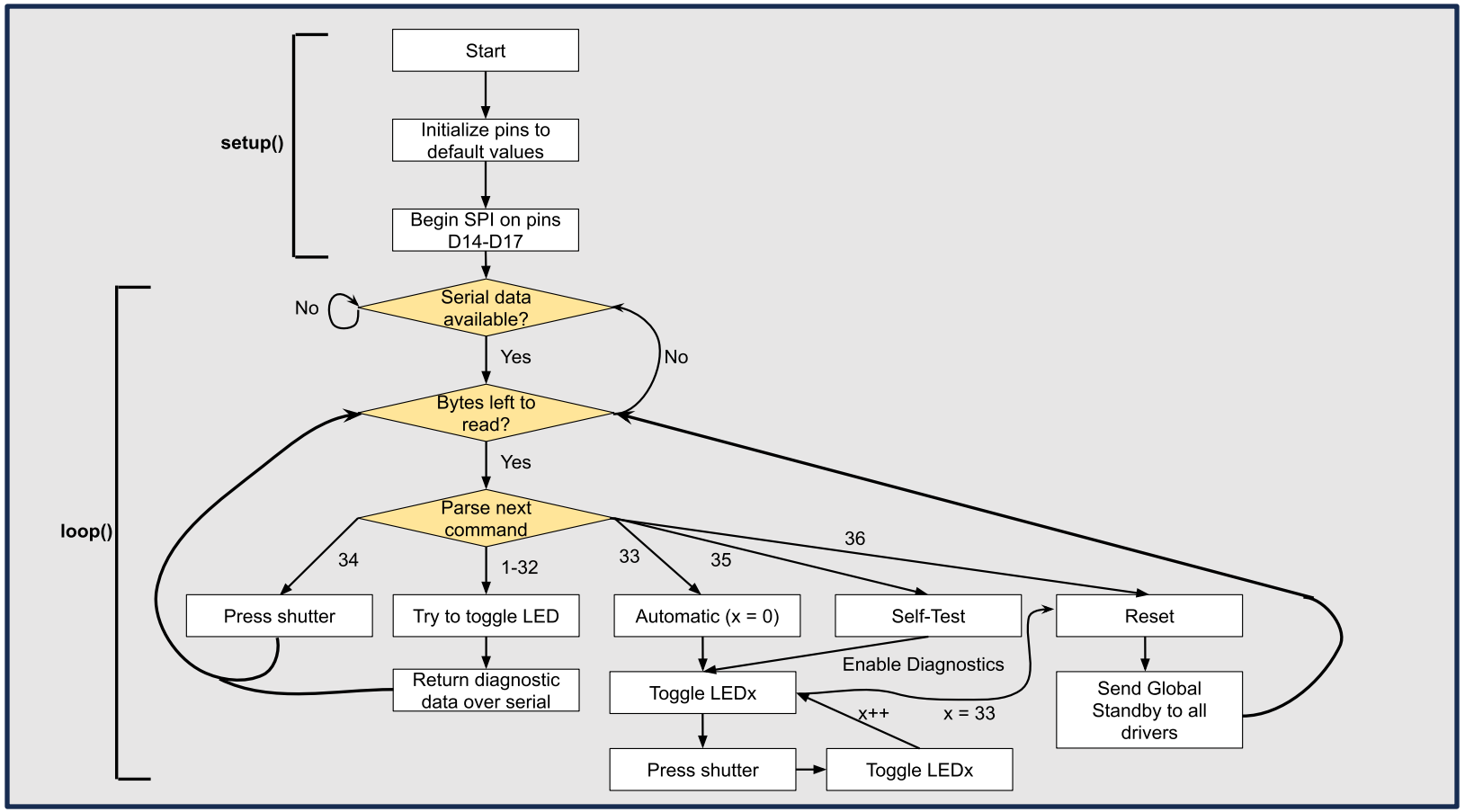
Two threads:

(1) **Listen** receives and processes information from PCB

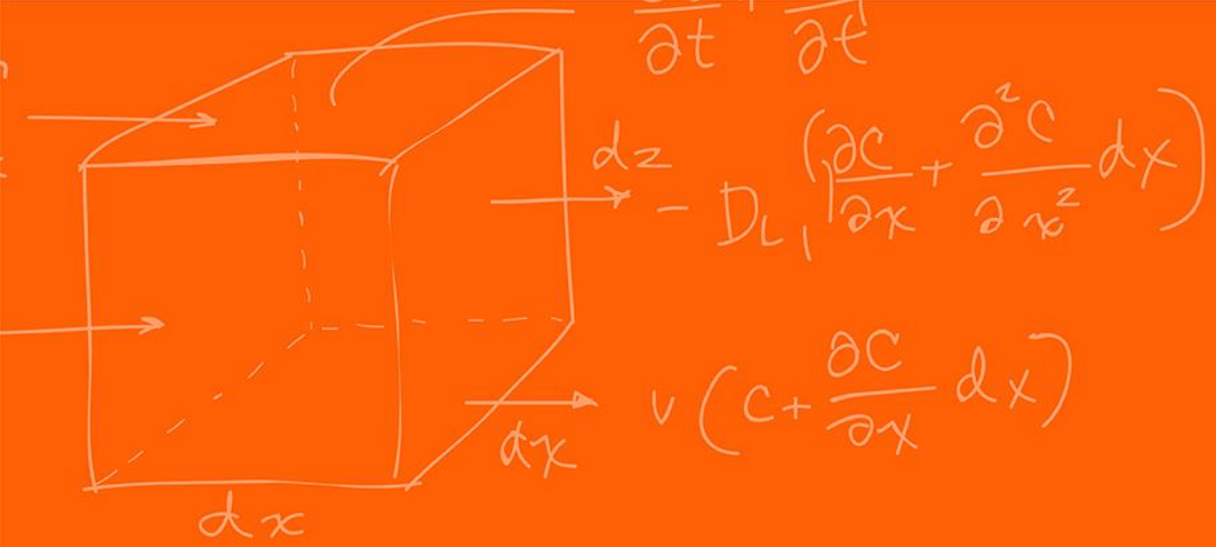
(2) **Send** sends commands to the PCB, and runs the GUI

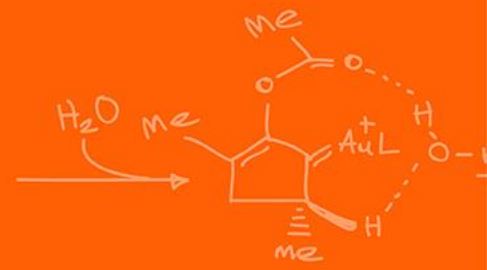


Arduino Code Flowchart

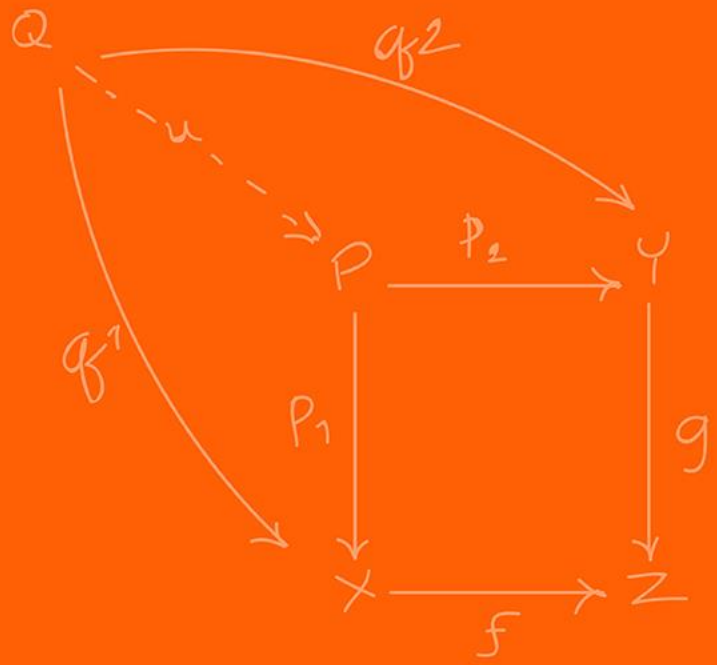


Flowchart of the Arduino software burned onto the ATMega32U4





Results



Set of PTM Images

... x32

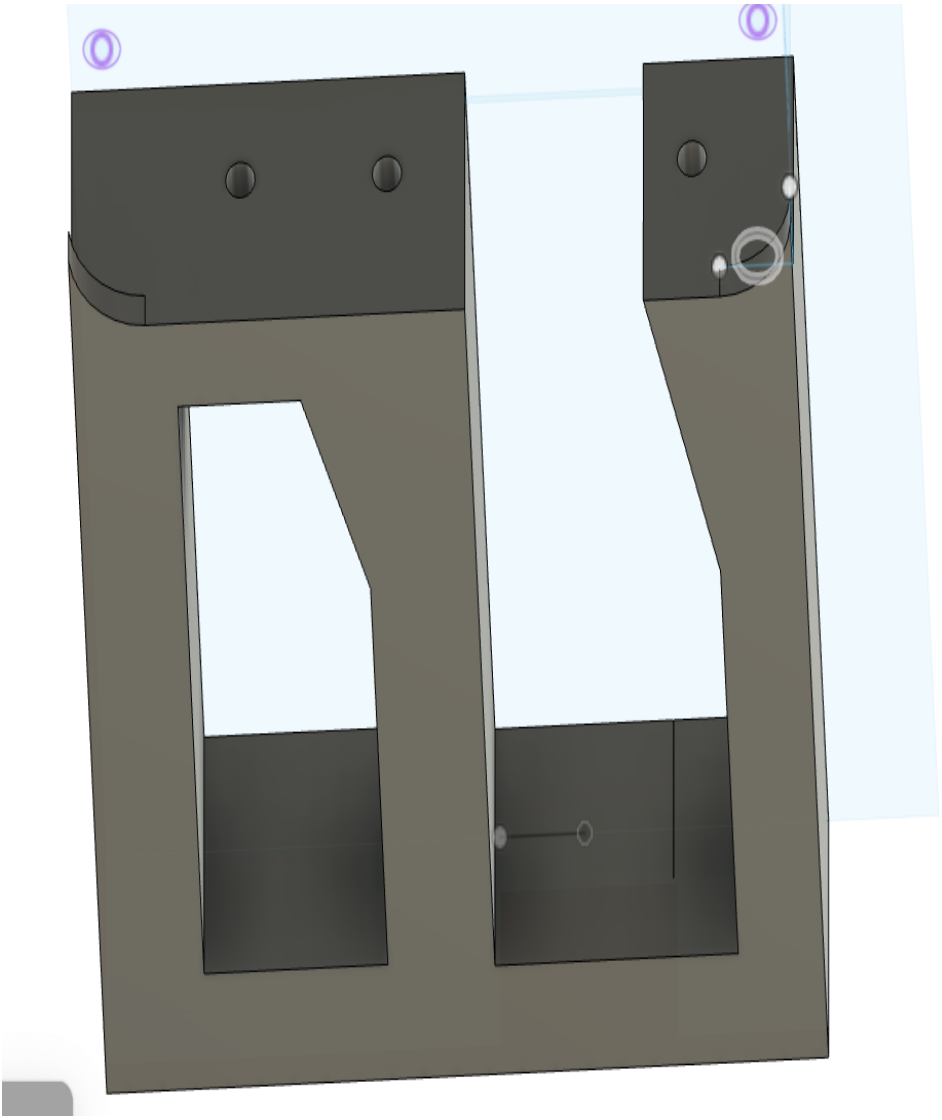
RTI Viewer Video

Control Enclosure

Custom Control Enclosure Design

- Fully **custom** 3D-printed enclosure made to precisely fit our PCB and provide **mechanical stability**
- Features **labeled cutouts** for all interfaces: Camera, USB-C, Power, LED connectors
- Made with PLA for durability, ESD resistance, and heat tolerance
- Includes ventilation slots on lid and base to maintain safe internal temperatures
- Fastened using **standard M3 screws into standoff inserts to avoid damaging the plastic**

Highlights of Technical Design Decisions



Support Structure:

- Side-mount bracket **elevates enclosure by 4 inches** off the wooden dome base
- Adds **structural rigidity** and protects cables from tension or bending
- Uses L-brackets to **prevent drilling into plastic**

Connector Layout:

- Routed to avoid crosstalk and enable EMI shielding
- Labeled for clarity and aligned with PCB silkscreen

Surface Labeling & Fit:

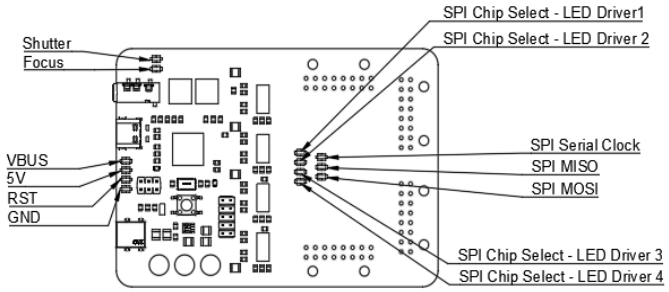
•All ports engraved directly on the enclosure for user guidance

•PCB is isolated from mechanical stress through internal standoffs

Longevity & Repairability

Designing for longevity means designing for repairability

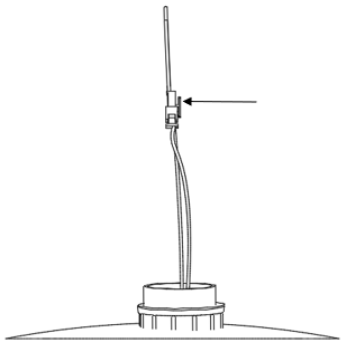
- Standard fasteners & components
- Minimal glue & adhesive
- Robust components
- Spare parts
- Repair Manuals
- Test Points on PCB

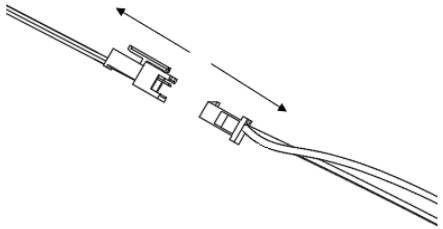


Repair & User Manuals are critical to longevity & repairability

Replacement Procedure – Lightbulb

1. Unplug the power from the Control Board.
2. Disconnect the lightbulb from the dome wire by pushing down on the tab, as shown below, and pulling the connector apart:





Troubleshooting Procedure – Multiple lights not turning on

Use this section to troubleshoot an issue with multiple LEDs not illuminating when the PC software calls for it. **This section assumes that the camera shutter control is working, and the PC software can connect to the Control Board. If either of those conditions are not met, this section will not resolve the issue. Refer to the "Board Not Responding to PC Input" section.**

1. **Try the simple things first –** Unplug & reconnect the power adapter from the Control Board and restart the computer with the software on it. Make sure the issue is not isolated to a single light. If it is, follow the steps in "Light not turning on (single bulb)."
2. **Isolate the issue –** When multiple bulbs fail, it is important to determine the type of failure using isolation testing.
   a. **Make sure the issue is not lightbulb-related -** If some lights are turning on, ensure that the issue is not just several lightbulbs that have failed. This is uncommon but possible, and it must be ruled out to avoid unnecessary troubleshooting. You can do this by swapping a bulb from a bad light with one from a light that is working. If the issue follows the bulb, there may be multiple failed bulbs. Try replacing all the bulbs that are not turning on. Again, this is unlikely to happen with more than two or three bulbs at the same time.
   b. **Run a software diagnostic –** Run a self-test in the PC software. This will determine whether there is an open circuit or a short circuit on any of the LED outputs. An open circuit means something isn't making a good connection, and a short circuit means something is connected to something it shouldn't be, or there is a control board issue. If several LEDs are diagnosed by the software as open circuit, make sure they are plugged into their individual connectors properly and the 16-pin LED connectors on the control board are plugged in securely.
   c. **Determine whether the issue is coming from one group of LEDs –** The LEDs are controlled by 4 separate drivers and grouped into 4 connectors with 8 LEDs each. If the number of failed LEDs is a multiple of 8, it's likely that the issue is coming from either one of the drivers or the connector on the control

Conclusion & Recommendations for Future Work

What We Learned

- Small electrical mistakes (like a floating pin) can completely break functionality
- Designing hardware isn't just about circuits—physical layout, usability, and maintenance access all matter
- Legacy systems often require workarounds and creative problem-solving rather than starting from scratch

What We'd Do Differently

- Standard LEDs for improving repairability

Recommendations for Future Work

- Separate PWM control lines on the PCB for independent dimming
- Coat the enclosure in ESD-resistant paint for added static protection
- Reprint the enclosure in PETG for better thermal and impact performance
- Extend GUI functionality to support brightness control
- Test and tune enclosure thermals under full load for better reliability

Questions