LED PERSISTENCE OF VISION GLOBE

By

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Abstract

The human visual system retains an image for a brief interval—approximately one-tenth of a second—after the stimulus is removed. This phenomenon, known as persistence of vision, arises from the delayed response of retinal photoreceptors and sensory neural circuits. For centuries, this property has been used to create motion illusions, from early optical toys to modern cinema. In this project, developed for ECE 445, we exploit the same principle to create a dynamic two-dimensional display using a single array of LEDs rotating on a spherical path, producing the illusion of a globe-shaped floating display. The final product's intended use is for UIUC's LabEscape, to display various graphics including clock time and clues through wireless communication in real time.

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1. Introduction

LabEscape at UIUC is a science outreach escape room with the mission of providing rewarding and thrilling experiences that show how science can be amazing, useful, beautiful, and fun. Their puzzles are built around real physical phenomena, giving visitors the chance to see science in action. When an exhibit does not work as intended, it can take away both the educational goals and the entertainment value that are central to the LabEscape experience.

1.1 Problem statement

Recently, the team attempted to create an LED globe that uses Persistence of Vision (**POV**) to display text, images, and animations. The project has run into several problems. The LEDs are not syncing with the motor's rotational speed, the motor seems to run faster than needed, even generating lift which makes the system unstable, and there is uncertainty about whether the correct voltage is being applied. With little documentation to reference, troubleshooting has proven difficult. On top of these issues, the team hopes to add more functionality, including the ability to display images and animations as well as control the globe remotely through WiFi. Solving these problems is important not only for the success of the project but also for maintaining LabEscape's mission of delivering science that both excites and educates.

1.2 Solution

Our solution is to design and build a stable, WiFi-enabled LED globe that reliably displays text, images, and animations using Persistence of Vision. At a high level, the system will synchronize LED patterns with the rotation of the globe to create clear visuals, while providing a user-friendly interface for uploading and managing content remotely. This approach directly addresses the synchronization, stability, and usability issues that have limited earlier attempts at the project [1] .

To implement this, the globe will use a 6V motor with a maximum output of 4000 rpm, paired with a hall effect sensor to track rotational position. The ESP32 microcontroller will use this feedback to precisely time LED updates, eliminating flicker and distortion. A microSD card will store image and animation files, allowing for more complex displays. The ESP32 will additionally provide WiFi connectivity for a web-based control app. Through this app, users will be able to upload content, adjust settings, and trigger animations in real time. The motor will draw power directly from an outlet, while the control electronics and LEDs will run from wireless regulated power to ensure stable performance. Together, these components create a system that not only solves the technical problems of synchronization and instability but also adds new functionality that makes the globe more interactive, engaging, and easy to maintain. By delivering a reliable and visually impressive exhibit, this solution will help LabEscape achieve its mission of creating unforgettable experiences that demonstrate the fun and wonder of science.

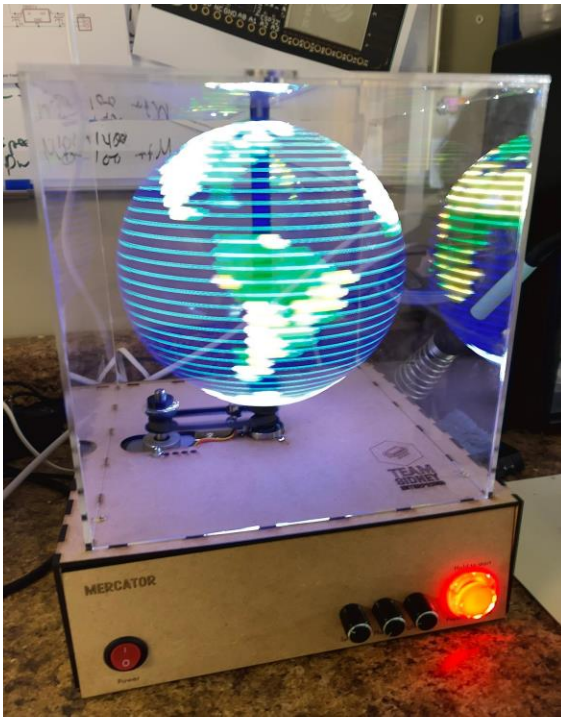

Figure 1. An example of persistence-of-vision globe developed by a hobbyist. Credit: Matt Walsh, Medium

1.3 High level requirements

Our POV Globe will satisfy the following high-level requirements:

1. **Resolution & Color:** The POV globe should display RGB images with 64x256 pixels resolution and 8-bit color. The images should remain stationary and clear to the viewer as the globe rotates continuously.

2. **Power**: The globe will be powered via a 12V, 3A power adaptor. The rotating segment containing the LEDs and circuit board will draw 25W through a slip-ring transformer – i.e. without an on-board battery.

3. **Data Transfer**: The rotating circuit board should wirelessly receive data and store it onto an onboard SD card. The system shall then read and display this data on the LED array in under 10 seconds.

2 Design

The design for the POV glob includes four subsystems, for power delivery, Controller Systems, Display Systems, and Wireless Systems.

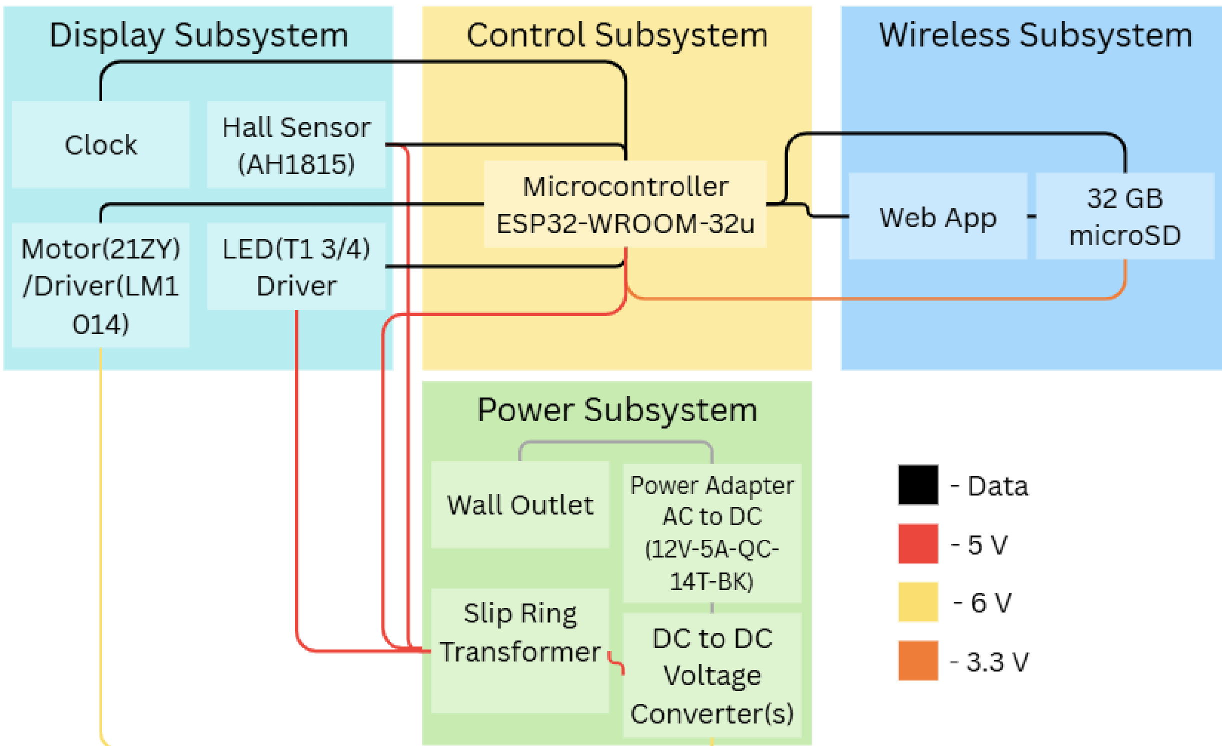

Figure 2: A block diagram indicating connections between components and subcomponents.

2.1 Display Subsystem

This system consists of a motor[1], hall sensor[2], LEDs[3], and clock. All of which are necessary to provide the logistical and mechanical needs to allow for a readable display. This subsystem interacts heavily with our microcontroller. 64 5mm 4 Pin LEDs make up the display. LEDs are in groups of 12 attached to LED drivers. Each group of 12 has their anodes connected to each of the 12 different pins. The LED driver[4] pulses 12 LEDs at a time using 36 pins, 3 per LED. The motor has to spin at 600 RPM and will have to

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[1] LEDs must achieve 256 distinct color levels

[2] Sparkfun Electornics. "Hall-Effect Sensor - AH1815 (Non-Latching)." *Sparkfun Electornics*, https://www.sparkfun.com/hall-effect-sensor-ah1815-non-latching.html.

[3] Envistia Mall. "5MM T1-3/4 4 Pin Common Anode / Common Cathode Clear / Diffused RGB LED." *Envistia Mall*, https://support.envistiamall.com/kb/5mm-t1-3-4-4-pin-common-anode-common-cathode-clear-diffused-rgb-led/.

[4] Kinetic Technologies, "KTD2061/58/59/60 – 36-Channel RGB LED Drivers with I2C Control (Rev. 04e, Mar. 2022)," *Kinetic Technologies,* 2022, https://www.kinet-ic.com/uploads/KTD2061-58-59-60-04e.pdf. Accessed 15 Oct. 2025

have solid mounting to the base as well as the LED board. The LED's will span 2/3rd of the surface of black globe that is used to eliminate background noise when viewing the display. 2/3rd was chosen as the implementation of any further spanning distance becomes logistically complicated regarding the mounting of the other systems.

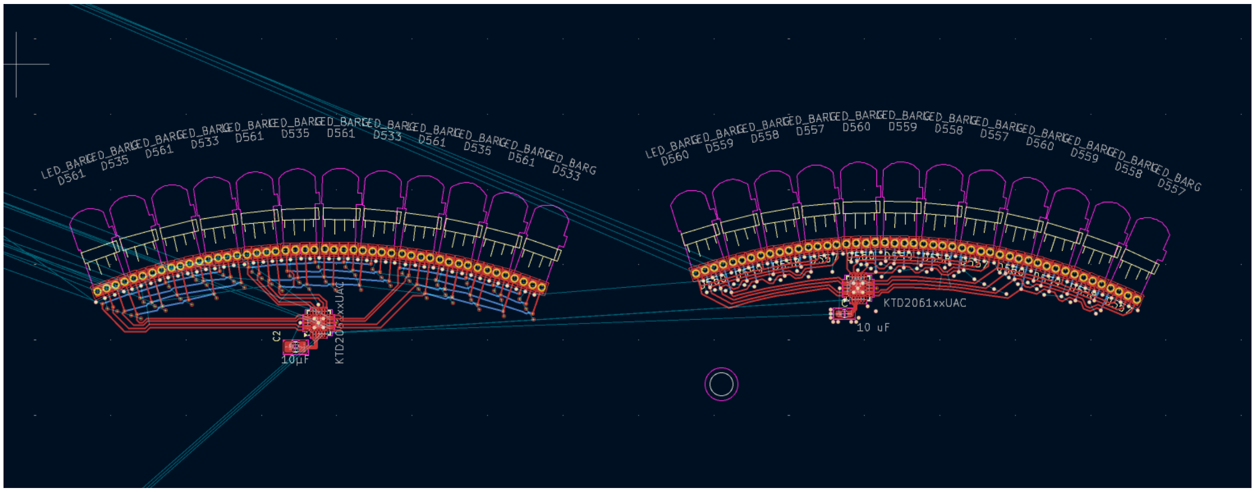

Figure 3: A snippet of how the LED's are spaced on a portion of the arch mentioned above.

2.1.3 Motor

The motor must spin the globe at a rate of 600 ± 15 RPM. This speed is necessary to achieve satisfactory persistence of vision as well as slow enough to avoid issues with the speed of LED addressability. The design uses a 31ZY Permanent Magnet Motor rated for up to 12V and 8000 RPM. For this reason, the motor will be run at a reduced voltage of 3V yielding a rotational speed of a maximum of 900 RPM. This speed is more than sufficient to provide persistence of vision and is still within the range to not outpace the speed at which we can write to the LEDs.

2.1.4 LEDs/Drivers

LEDs must achieve 256 distinct color levels. Utilizing our LED decoders, we will be able to ensure proper addressability of each LED and its color. In order to address all our LEDS individually, we will need to construct a 6 to 64 decoder utilizing 4 4 to 16 decoders and a 2 to 4 decoder. There will then be 3 pins dedicated to color channels which will be fed into each LED. The LED's we will be using are the 5MM T1-3/4 4 Pin Common Anode.

2.2 Control Subsystem

This subsystem consists of our ESP32[5] microcontroller which will hold the logic and do all calculations necessary to display items on our LED display. As mentioned later in tolerance analysis, the system is able to handle all necessary calculations in the time allotted. This system also includes all code

[5] ESPRESSIF. "ESP32-WROOM-32U." *Espressif Systems*, https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32d_esp32-wroom-32u_datasheet_en.pdf. Accessed 12 October 2025.

structures that were built in order to properly handle image data, pixel data, and synchronization systems. These had to be structured in such a way as not to interfere with one another. Specifically, the synchronization system demands constant authority. To accomplish this, the design utilizes the multicore of the ESP32 to constantly run checks for the hall sensor in the design all the while the second core continues running display systems relying on the previous data collected from the first core. This System also utilizes a hall sensor to be able to effectively synchronize patterns to prevent them from drifting accross the display.

2.2.1 Microcontroller ESP32

The ESP32 being used has 21 GPIO pins and 2 cores. The two cores are utilized to run synchronization software and LED pattern logic simultaneously. The 21 GPIO pins are utilized for interfacing and power. Each GPIO has PWM capabilities which allows for the customization of intensity and color as it relates to individual pixels that must be represented. As mentioned previously the multicore allows for a live synchronization system without sacrificing image display quality. The onboard 520 KB of SRAM of the ESP32 also allows for the buffering of image data for easy and fast access speed of 100 Mb/s, for effective display to our spinning LED's.

2.3 Wireless Subsystem

The wireless subsystem enables remote interaction with the globe through the ESP32's integrated Wi-Fi capabilities. The ESP32 is configured to operate as a client on an existing local network (LabEscape's private network or a staff mobile hotspot). This allows authorized users to connect to the globe from any device on the same network without requiring physical access. While password protection is not strictly required for basic operation, the final system will include optional credential-based access to prevent unauthorized control when deployed in public spaces. Through this wireless interface, staff can upload new images, select stored images for display, and send text to be rendered directly on the LED array. The wireless connection is expected to remain stable for extended operation, as the globe may be powered continuously during exhibitions.

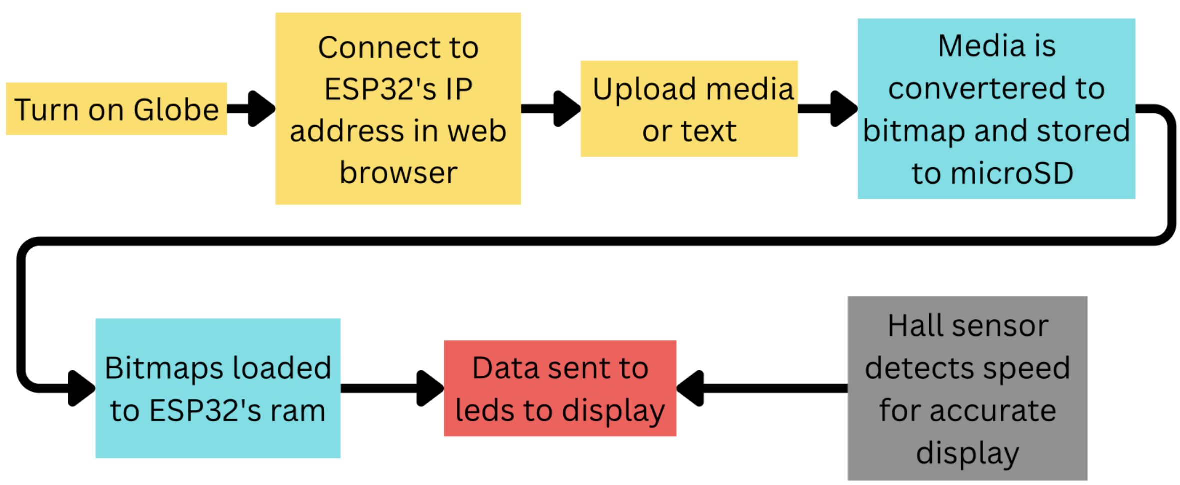

Figure 4: Flow Chart indicating the path our user's would take to display media on the globe

2.3.1 Web App

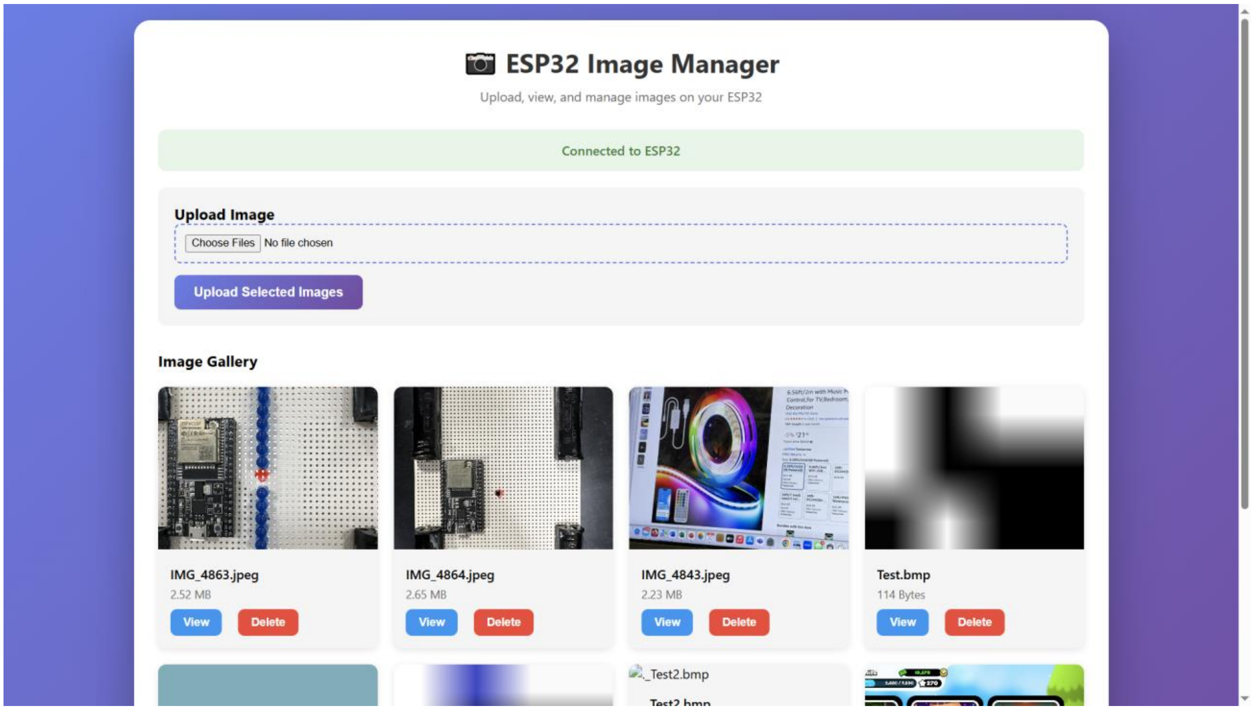

Figure 5: The current iteration of the Web Application

The web application provides the primary user interface for managing visual content on the globe. When accessed through a browser, the application displays a list of image files currently stored on the microSD card and allows staff to upload new assets. To ensure proper alignment with the physical LED layout, all images must be formatted to 64×256 pixels in BMP format. The web app will either (1) automatically convert uploaded images to the required resolution and BMP encoding, or (2) direct staff to a built-in or external conversion tool during upload. This ensures that every stored file matches the display subsystem's expected pixel mapping and can be rendered without additional processing or visual distortion. The interface will also include a text input field for quickly displaying custom messages. Instead of converting text to an image, the ESP32 renders text directly using a preprogrammed bitmap font stored in flash. This avoids unnecessary file generation and reduces latency for text-based updates.

2.3.2 MicroSD

The microSD card serves as the storage medium for all displayable visual assets. Each stored image is a 64×256 BMP, ensuring a consistent pixel layout for direct mapping to LED positions. When an image is selected for display, the ESP32 loads the BMP data from the microSD card into RAM, allowing the display subsystem to retrieve pixel values at high speed during rotation. This prevents timing artifacts that would occur if the system attempted to stream directly from the SD card while the globe was spinning.

Typical BMP files at this resolution are expected to be under 500 kB, which allows the SD card to store many static images along with additional multi-frame sequences for simple animations or GIF-style effects. Images are selected by filenames through the web interface.

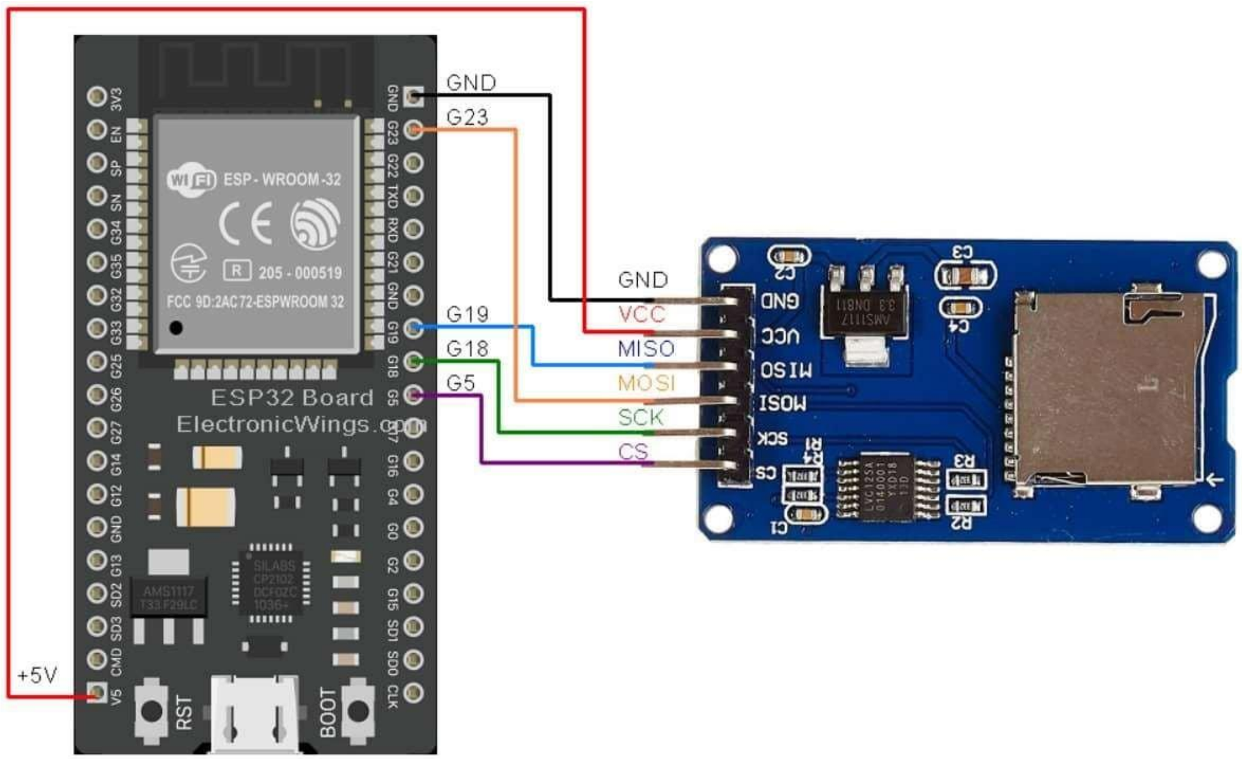

Figure 6: MicroSD module hooked up to ESP32. Credit: ElectronicWIngs

2.4 Power Subsystem

The power subsystem begins at a 120V power supply. From here a power converter is used to step down our voltage from 120V to 5V. This voltage will then be stepped down further to 3V in order to supply the motor with the adequate voltage as mentioned in the Tolerance analysis section and the motor section above. From the 5V line we will run that into a slip ring which will then transfer power to the spinning part of the design. The 5V will be used to power the microcontroller and SD card unit. The slip ring is a central component to this design as it ensures that we can provide proper power to the microcontroller and SD card unit that manages all our LED logic and display systems.

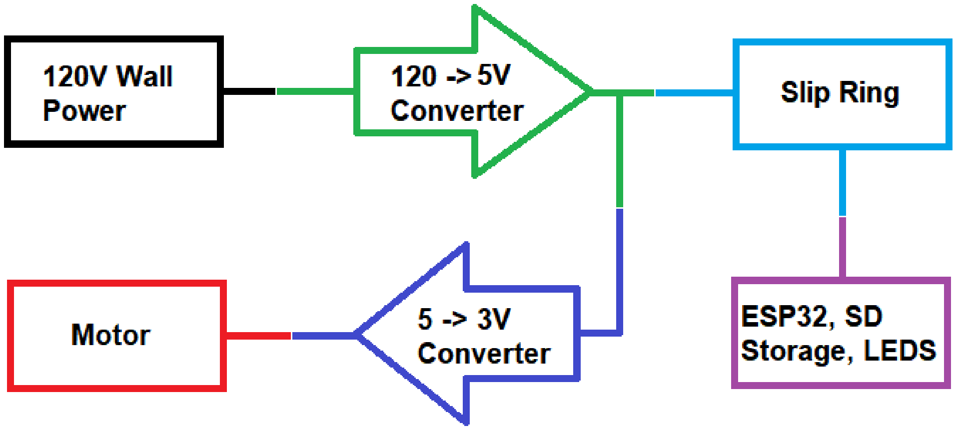

Figure 7: A visual depiction of the flow of power between the different major modules in the design

3. Design Verification

If all systems are working properly we will test whether we are able to upload a set of images wirelessly and display those images properly onto our LED display. Properly implies the proper positioning of pixels from our respective images onto our rotating sphere of LED's. Verification for each subcomponent is as follows:

3.1 Display Subsystem

Requirements	**Verifications**
The motor must spin the globe at a rate of 600 ± 15 RPM	Using the system's hall sensor and magnet, the speed of the motor is polled every 10 seconds for a 5-minute continuous run to make sure it remains in the acceptable range.
The display must render frames with a less than 5% flicker	Using an oscilloscope, we will sample the LED PWM signals and compare them to the timing
LEDs must achieve 256 distinct color levels	Verify with an oscilloscope that the PWM voltage levels is between 0.33-3.84 V

Table 1: Requirements and verification for the display subsystem.

3.2 Controller Subsystem

Requirements	**Verifications**
LED control loop must complete in less than 1 ms per iteration	Using the ESP32's built in microsecond counter, we can wrap the LED update logic with timestamp reads and view them in the serial terminal

SD card must support a read rate greater than 1 MB/s	Run a transfer test with different sized files (5, 50 and 500 KB) to see how fast a file is read. By utilizing the built in timing functions provided by arduino IDE. As long as these timings are above 1 MB/s, our condition is met.

Table 2: Requirements and verification for the Controller Subsystem.

3.3 Wireless Subsystem

Requirements	**Verifications**
The time from a WiFi command (e.g., image change) being sent until the first pixel is updated must be $\leq$ 3 seconds.	Timing the web app input up until the globe changes to what the input indicated.
Microcontroller must hold a steady connection for at least 2 hours	Run a script that periodically sends and receives data from the web app for a couple of hours, logging it in a serial terminal.

Table 3: Requirements and verification for the wireless subsystem.

3.4 Power Subsystem

Requirements	**Verifications**
Voltage for LED PCB and main PCB must be 5V $\pm$ 0.2 V	Using a multimeter, we'll measure the PCB's output voltage under load
PCB must draw less than 6 A as the total current	Using a multimeter, we'll measure the current being supplied to the PCB while in operation

Table 4: Requirements and verification for the power subsystem.

4. Tolerance Analysis

The breaking point of our project is the speed at which we can write information to our LEDS relative to our spin speed. The fastest location we can draw pixel data from is our ESP32's onboard memory where it can be accessed at fast enough speeds relative to the rotation of our board. See math below.

We anticipate a maximum spin speed of 1200 RPM. This results in an RPS of…

20 RPS = 1200RPM / 60s

This results in a 1 rotation every 0.05 of a second. Our ESP32's memory can be read at a safe value of 100 Mb/s. Our images will be formatted to 256x64 pixels. Therefore, we will want to be updating our color information for pixels every…

Seconds per Image Column = 0.05s / 256 columns

The maximum size of our images are roughly, as determined by experimentation via the creation and analysis of multiple 256x64 BMP files, 48 KB large. We will need to read at maximum 48000/256 bytes of information each time as only one column is relevant per segments. As long as the time to read required information is less than the amount of time available to read the information (0.05/256), we will be able to read all necessary data from onboard memory and display it in a timely manner.

Time to Read New Data = (48000/256)/100000000

Available Time to Read Data = (0.05/256)

Time to Read New Data < Available Time to Read Data

Therefore, we know that our system is viable. Additionally, this math yields the information needed to display any 256x64 image. By timing which LEDS map to which pixels at a given relative time on their revolution, we can map all 16384 pixels to an LED per rotation.

5. Costs

The cost of our project includes the many components we will have to purchase as well as the cost of PCB orders and labor costs.

5.1 Parts

Table 5 Parts Costs

Part	Manufacturer	Retail Cost ($)	Amount	Actual Cost ($)
Hall-Effect Sensor - AH1815 (Non-Latching)	Sparkfun	$1.05	1	$1.05
Led Driver KTD2061	Kinetic Technologies	$1.66	6	$9.96
Neodymium Magnet Disk Sensor N35 D6mm(A) x 3mm	Radial Magnet	$1.00	1	$1.00
31ZY Permanent Magnet Motor, 6V/12V/24V 3500-8000RPM Permanent Magnet DC Motor Electric Brushed Motor CW/CCW (12V 8000RPM)	Robot Shop	$16.91	1	$16.91
5MM T1-3/4 4 Pin Common Anode / Common Cathode Clear / Diffused RGB LED	Chanzon	$0.09	100	$9.00
LM1014 Motor Speed Controller	National Semiconductor	$5.72	1	$5.72
ESP32-WROOM-32U	Digikey	$4.84	1	$4.84
12 V, 5 A AC-DC Power Jack	Gilivier	$9.98	1	$9.98
SanDisk Ultra PLUS 32GB microSD Memory Card[6]	SanDisk	$14.99	1	$14.99

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Target. “SanDisk Ultra PLUS 32GB microSD Memory Card.” *Target*, https://www.target.com/p/sandisk-ultra-plus-32gb-microsd-memory-card/-/A-14413251. Accessed 2 November 2025.

Slip Ring with Flange - 22mm diameter, 6 wires, max 240V @ 2A[7]	Adafruit	$14.95	1	14.95
Total				$88.40

5.2 Labor

According to the Grainger College of Engineering[8] graduates with a computer engineering degree earn on average $57.09/hr. Assuming that we spend a maximum of 70 hours working on this project we get a total cost of labor of:

$$70 \times \$57.09 = \$3996.30$$

[7] Adafruit. "Slip Ring with Flange - 22mm diameter, 6 wires, max 240V @ 2A." *Adafruit*, https://www.adafruit.com/product/736. Accessed 2 November 2025.

[8] Grainger College of Engineering. "Computer Engineering." *The Grainger College of Engineering, University of Illinois Urbana-Champaign*, https://grainger.illinois.edu/academics/undergraduate/majors-and-minors/computer-engineering. Accessed 13 October 2025

6. Conclusion

6.1 Accomplishments

We have accomplished quite few exciting feats so far in our testing. Namely we have accomplished proper persistence of vision, multicore control via the ESP32 allowing for proper image synchronization, algorithm to translate pixels from an image onto our spherical design, and remote storage of images.

6.2 Uncertainties

We have a couple of uncertainties as to the writing of this document, particularly regarding the desgin of a power conversion system for our motor. In practice we ran our motor at about .42 amps which was sufficient for our breadboard prototypes. However, for our final design this number will likely be different. Therefore, we are uncertain as to when we will be designing this circuit that will regulate the power into our system. This will likely happen once we have finalized our design, but if that proves to be unrealistic, we will likely design a power conversion system that will supply a satisfactory result. As our system is designed to adjust to different speeds within reason, this is an acceptable option.

6.3 Ethical Considerations

6.3.1 Ethics

The development of our LED globe project involves several ethical considerations. We prioritize the safety, health, and welfare of the public by ensuring that the device is electrically safe, mechanically stable, and responsibly designed. The purpose of the globe is to serve as an engaging and educational demonstration of Persistence of Vision, which supports LabEscape's mission of using science to inspire curiosity and learning.

A key ethical concern is privacy and security, since the device can be controlled remotely over WiFi. Without safeguards, unauthorized individuals could connect to the globe and display inappropriate or misleading messages during public demonstrations. To prevent this, we will implement password protection and restrict control access so that only LabEscape staff can update the display. By being transparent about how the system works, documenting our security measures, and providing clear guidelines for responsible use, we will reduce the risk of intentional misuse.

6.3.2 Safety

- **Electrical Safety**
  The globe relies on a high-speed 6V motor powered from an outlet, a microcontroller, LEDs, and a WiFi module. To minimize electrical risks such as overheating, short circuits, or accidental shock, the system will use proper voltage regulation, fuses, and insulation. All wiring and connections will be securely enclosed, and the power supply will be housed in a protective casing to prevent accidental contact. During development, we

will follow standard lab safety practices, including the use of insulated tools and protective eyewear when soldering.

- **Mechanical Safety:**
  Because the motor could spin at hundreds or even thousands of revolutions per minute, mechanical stability is a priority. The globe will be securely mounted and balanced to avoid vibrations that could damage components or cause parts to detach. A protective housing will be added around the rotating assembly to reduce the risk of accidental contact during operation. The mounting system will also be tested to ensure it remains stable even during extended demonstrations.
- **End-User Safety:**
  Since the project is intended for public demonstrations, the device will always be operated under supervision. Users will not have direct access to the motor or electronics, and clear instructions and warnings will be provided to minimize risks. Security measures such as password protection on the WiFi interface will ensure that only authorized staff can change the display. Additionally, flashing lights and animations can trigger seizures in individuals with photosensitive epilepsy, so visible warnings will be posted near the exhibit to alert visitors before use. Together, these precautions ensure the globe remains both safe and reliable in an educational setting.

6.4 Future work

Week	Task	Responsibility
Oct 27th – Nov 3rd	Receive and Begin work on PCB order. Build power converter from wall socket to device.	Melvin
Oct 27th – Nov 3rd	Compile all code snippets including Wifi Connectivity, Image Display, and Spin Synchronization into one full program. Complete logic for mapping pixels onto 64 LEDS.	Gavi
Nov 3rd – Nov 10th	Finish assembly of initial PCB order and test initial system.	Gavi
Nov 3rd – Nov 10th	3D print supporting structures for device. Deadline to complete compiling errors and fixes for next PCB order. Complete web app, making sure it functions as intended,	Melvin
Nov 10th – Nov 17th	Finish assembly of second PCB order and test remaining systems.	Melvin, Gavi

Nov 17th – Nov 24th	Mock Demo. Extra time for improvements	Everyone
Nov 24th – Dec 1st	Thank sgiving Break	Noone
Dec1st – Dec 8th	Final Demo	Everyone
Dec 8th – Dec 15th	Final Presentations	Everyone

Table 6: A table describing our schedule for the upcoming weeks.

References

[1] ACM. ACM Code of Ethics and Professional Conduct. Association for Computing Machinery, 2018, https://www.acm.org/code-of-ethics. Accessed 19 Sept. 2025.

[2] Kinetic Technologies, "KTD2061/58/59/60 – 36-Channel RGB LED Drivers with I2C Control (Rev. 04e, Mar. 2022)," *Kinetic Technologies,* 2022, https://www.kinet-ic.com/uploads/KTD2061-58-59-60-04e.pdf. Accessed 15 Oct. 2025

[3] "Flicker Fusion Threshold." Wikipedia: The Free Encyclopedia, Wikimedia Foundation, 19 Aug. 2025, en.wikipedia.org/wiki/Flicker_fusion_threshold . Accessed 19 Sept. 2025.

[4] IEEE. "IEEE Code of Ethics." IEEE Policies, IEEE, https://www.ieee.org/about/corporate/governance/p7-8.html. Accessed 19 Sept. 2025.

[5] Rasberry Pi. "Buy an RP2040 – Raspberry Pi." Raspberry Pi, https://www.raspberrypi.com/products/rp2040/. Accessed 19 September 2025.

[6] Grainger College of Engineering. "Computer Engineering." *The Grainger College of Engineering, University of Illinois Urbana-Champaign*, https://grainger.illinois.edu/academics/undergraduate/majors-and-minors/computer-engineering. Accessed 13 October 2025

[7] Amazon. "31ZY Permanent Magnet Motor, 6V/12V/24V 3500-8000RPM Permanent Magnet DC Motor Electric Brushed Motor CW/CCW (12V 8000RPM)." *Amazon*, https://www.amazon.com/Permanent-Magnet-3500-8000RPM-Electric-Brushed/dp/B07G5GRKFG?th=1.

[8] Envistia Mall. "5MM T1-3/4 4 Pin Common Anode / Common Cathode Clear / Diffused RGB LED." *Envistia Mall*, https://support.envistiamall.com/kb/5mm-t1-3-4-4-pin-common-anode-common-cathode-clear-diffused-rgb-led/.

[9] ESPRESSIF. "ESP32-WROOM-32U." *Espressif Systems*, https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32d_esp32-wroom-32u_datasheet_en.pdf. Accessed 12 October 2025.

[10] National Semiconductor. "LM1014 Motor Speed Regulator." *National Semiconductor*, https://datasheet.octopart.com/LM1014N-National-Semiconductor-datasheet-180878907.pdf.

[11] Sparkfun Electornics. "Hall-Effect Sensor - AH1815 (Non-Latching)." *Sparkfun Electornics*, https://www.sparkfun.com/hall-effect-sensor-ah1815-non-latching.html.

[12] Target. "SanDisk Ultra PLUS 32GB microSD Memory Card." *Target*, https://www.target.com/p/sandisk-ultra-plus-32gb-microsd-memory-card/-/A-14413251. Accessed 2 November 2025.

[13] Adafruit. "Slip Ring with Flange - 22mm diameter, 6 wires, max 240V @ 2A." *Adafruit*, https://www.adafruit.com/product/736. Accessed 2 November 2025.