NASA TSGC Design Challenge: Reconfigurable Lighting System

Cullen College of Engineering | 832-466-6604 | hecarrer@cougarnet.uh.edu

December 17th, 2022

Team #6

University of Houston

Dear Dr. Mayerich,

Attached is the final written report for the Reconfigurable Lighting System this semester. All research, data and results are included. We met all deadlines. It has been a pleasure working with you. Thank you.

Sincerely,

Hector Carrera (Team Leader), Christopher Andrew, Christopher McLoughlin, & Jackson Clark

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Final Written Report

17 December 2022

Team #6

Faculty Advisor: Dr. Mayerich

Project Manager: Dr. Pei

Team Members: Hector Carrera (Team Leader), Christopher Andrew, Christopher McLoughlin, Jackson Clark

Background

In a professional lab environment, lighting can be the difference between a successful experiment and cataclysmic disaster. While lighting is important for normal labs, like those found on college campuses, lighting is even more important in a hostile environment like space. Currently, lighting in space consists of bulky fluorescent-tube light bulbs fixed to points in the cabin. While this does produce adequate light for work, it lacks in many other areas. First, the lights in the space station are fixed in place and cannot be used in any location that they are not attached to. Second, basic repairs for the standard lighting system are limited to changing the bulb in the device, but If that does not work, more advanced electrical work would be required to find and repair the damage. Finally, the standard lighting in the space station produces light that can disrupt the natural circadian rhythm of the occupants.

Proposed Solution

The solution to these problems is a new lighting system that is created with these problems in mind. The new lighting system will be portable and allow the user to mount it on many different surfaces without the need for an outlet in the immediate area. The lighting system will also allow the user to easily access, replace, and repair any part within the device with little technical expertise. The structure of the device will also be able to be printed on a 3D printer in the event that the device's structure is destroyed. Lastly, the new system will account for the circadian rhythm of the occupants. Standard fluorescent tube light bulbs produce light that has a "cold" color temperature. This means that the light contains lots of blue/white color in it. While this works well in a work environment, blue/white light causes those exposed to it feel less tired when they might be trying to sleep/relax. The new lighting system will not only produce cold light for working environments, it will be able to produce "warm" (yellow/daylight) light for leisure.

Patent Research and Search Results

We have researched patents which are related to our project, found differences and similarities and potential conflicts with the potentization for the project…

Patent 1 (US9820350B2)

Patent Name: CONFIGURABLE LIGHTING SYSTEM

Filed on: February 19, 2016

Abstract: "*A system can configure a luminaire for providing illumination of a selected color temperature , a selected lumen output, or a selected photometric distribution . The luminaire can comprise at least two light sources that have different illumination characteristics , for example different color temperatures, different lumen outputs , or different photometric distributions. The system can configure the luminaire to operate a first of the two light sources , a second of the two light sources , or both of the light sources based on an input. When the luminaire is configured to operate both of the light sources , the luminaire can produce illumination having a color temperature , a lumen output, or a photometric distribution that is different than either of the two light sources."*

Similarities:

- LED driver circuitry that relies on the use of enhancement mode N-channel MOSFETS
- Lighting configurability based on the use of 2 sets of LEDs with different illumination characteristics

Differences:

- The patent's control circuit is made with logic gate ICs, while our device's control circuit is implemented through the use of a microcontroller
- The patent only has 4 states of lighting operation (off, LEDs 1 on, LEDs 2 on, and LEDs 1&2 on), our device allows for a continuous range of operation controlling both the correlated color temperature and brightness
- The patent's operation states use a continuous steady DC voltage, and our device implements the us of microcontroller driven PWM signals to drive the LED circuits

Relevance:

- The means of creating a range of lighting possibilities are very similar

- Overall concept is very similar

Patent 2 (US011483908B1)

The information for this patent is below…

Patent name: 3-Way Dimming Brightness and Color Temperature Control

Filed on: May 25, 2021

The abstract is below…

(57) **ABSTRACT**

Disclosed embodiments provide a luminaire device including a power supply, and a three-way light module installed within a housing. The device includes an input end which is connected to the power grid, and an output end is connected to a three-way LED light module through the power supply and a control module, and an LED driver. The group corresponds to the series connection current module. The device also includes a dimmer, the output of the dimmer is connected to the power input of the lamp, and the power output is passed through a signal detection unit. A centralized control unit such as a microcontroller receives the adjustable signal of the dimmer, and the controller controls the current modules of the 3 LED modules. This enabled the feature of precise adjustments of brightness and correlated color temperature (CCT) of the device.

18 Claims, 7 Drawing Sheets

This patent has many differences and similarities including:

- Similarities include:
  - Similar electrical schematic
  - Similar control of LED through color temperature
- Differences include:
  - Simpler and discrete LED controller and control module
  - More LED modules.
  - No use of discrete transistors or voltage regulators
  - Discrete signal detection unit
- Relevance:
  - Very similar to our project
  - Similar control of LEDs and electrical design

Patent 3 (US011072110B2)

Patent name: 3D Printing of Objects with Optical Functional Surfaces

Filed on: Jul. 27, 2021

Abstract:

A method for 3D printing an object with at least one wall (**2**) having a first surface and a second, opposite surface, wherein the first surface is intended to serve as an optical functional surface, wherein the wall is formed by printing one track (**16**) on top of another track (**17**). An orientation of the object during printing is selected such that the wall has a tangent (or tangent surface) non-parallel to the z-axis, such that the first surface faces away from the x-y plane and the second surface faces the x-y plane. According to the invention, the 3D object is thus oriented during printing such that the first surface, intended to be used as an optical functional surface, faces away from the x-y plane, i.e. typically away from the support or platform on which the 3D object is printed upon. By ensuring this orientation during printing, the first surface becomes smoother than the second, opposite surface of the wall.

Similarities:

- Both the patent and the reconfigurable lighting system try to get the smoothest and clearest prints from a standard 3D printer

Differences:

- This patent only applies to a specific 3D printing process
- The reconfigurable lighting system being printing with PLA and not photopolymer

Patent 4

Patent name: Voltage Supply to a Load and Battery

Filed on: Aug. 7, 2020

Abstract:

Implementations described and claimed herein provide systems and methods for supplying voltage to a load and battery. In one implementation, a first regulated DC-to-DC converter is electrically connected to a first energy source to down convert a first voltage supplied by the first energy source. A load is electrically connected to the first regulated DC-to-DC converter to receive the down converted first voltage. A second regulated DC-to-DC converter is electrically connected to the first regulated DC-to-DC converter to regulate the down converted first voltage to a second voltage. A second power source is electrically connected to the second regulated DC-to-DC converter to charge the second power source using the second voltage, and the second power source is switchably connectable to the load.

Simila

- Similar electrical schematic for power section
- Similar needs created it

Differences

- Input voltage
- Load types
- Battery charging style

Overview Diagram

In order to simplify the project and make assigning work easier the project was broken up into 3 primary tasks with multiple sub tasks. Task 1 is composed of sub tasks related to the physical design of the project, shell, and mounting of electronics. Task 2 is composed of sub tasks related to the electrical design of the project, power, battery management, and component selection. Finally task 3 are software tasks, LED Controls, I/O, and usb communication. Figure 1 below shows the overview diagram flowchart.

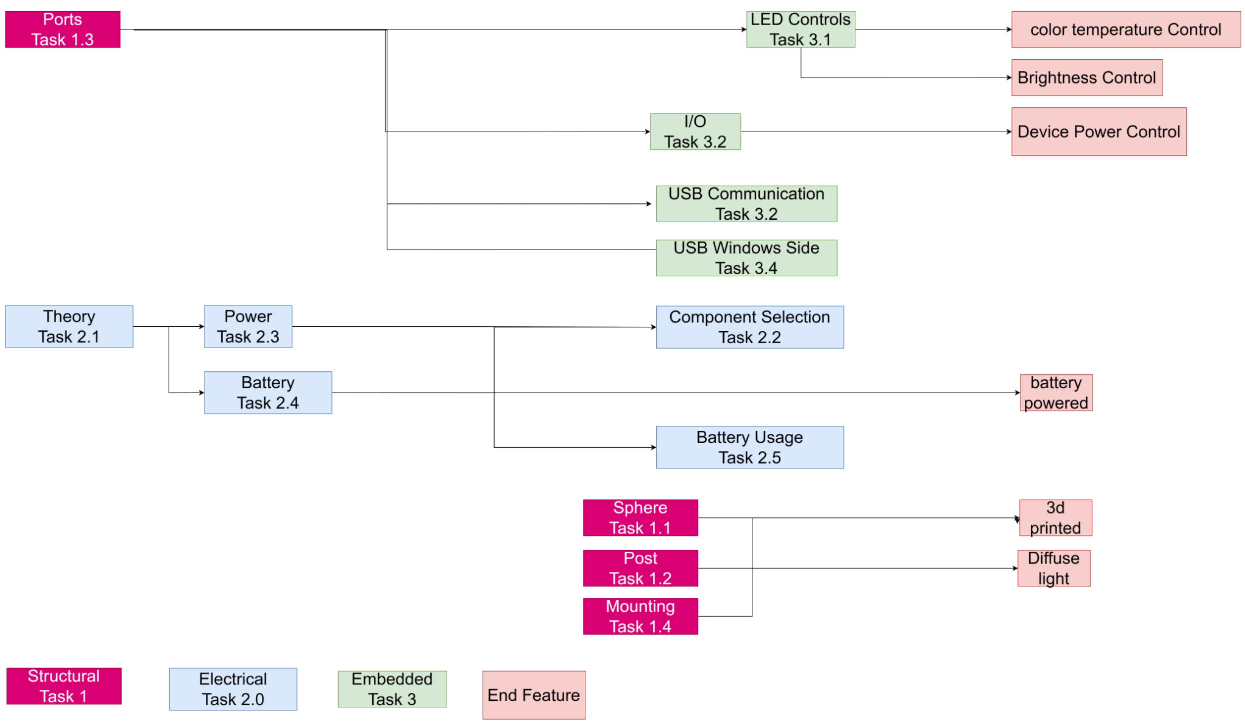


Figure 1: Overview Diagram

Deliverables

Aside from the features of the device, which are shown below, there will be three deliverables across the semester, being two prototypes and the final design. This is a deliberate approximation for the contractual terms for the project with the sponsor. Below are the deadlines:

1. **Prototype I – Nov 11 - met**
    a. Components inside structure
    b. Doesn't have to fully work (ideally it should)
    c. Discuss takeaways and improvements
2. **Prototype II – Nov 25 - met**
    a. Further testing and improvements of the first prototype
    b. At this point, everything should be mostly working
    c. Discuss takeaways and final improvements for the final design
3. **Final Design – Dec 2 - met**

Specific deliverables include:

- The "Orb"
    - Shell
    - 60 internal LEDs that meet specifications
    - 12 [V] battery
    - Magnetic latch
    - USB-A port
    - Internal TIVA-C
- USB Charging Cable and Adapter

A Gantt chart that shows a graphical representation of the deadlines for the deliveries was created. The red line indicated the current (at the time of writing) date. This Gantt chart is shown below in Figure 2.

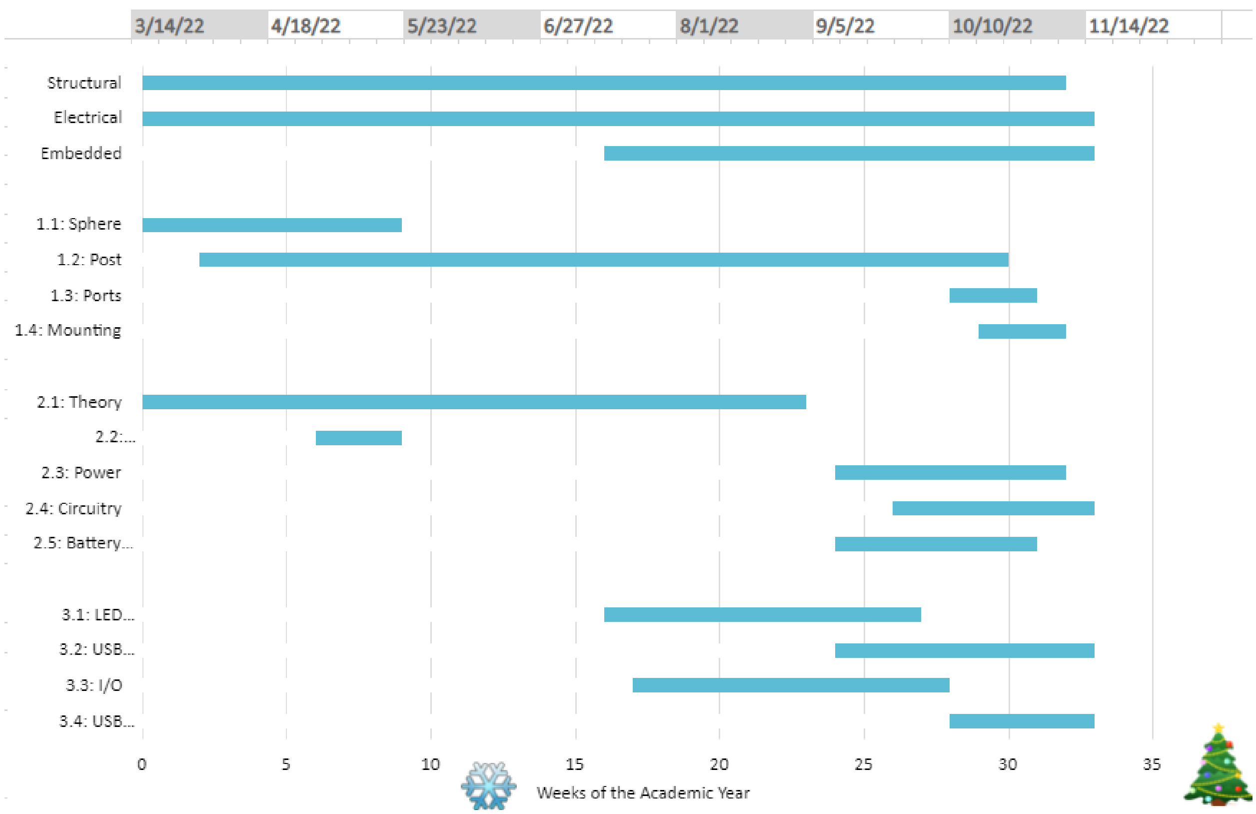


Figure 2: The Gantt chart for the reconfigurable lighting system's deliverables.

We actually met all deadlines, so the Gantt chart was not modified. We completed the final design by the due date.

Task Schedule and Task Leads

- **Structural**

  Lead Engineer: Christopher McLoughlin (All subtasks lead by Christopher McLouglin)
  - **1.1 Create sphere structure:** Completed on 04/10/22
  - **1.2 Create mounting post:** Completed on 10/03/22
  - **1.3 Add slots for electronic ports and buttons:** Completed on 10/28/22
  - **1.4 Add magnetic mounts to the device:** Completed on 11/04/22
- **Electrical**

  Lead Engineer: Jackson Clark & Hector Carrera
  - **2.1 Figure out the electrical theory for the device:** Lead by Jackson Clark and completed on 08/11/22

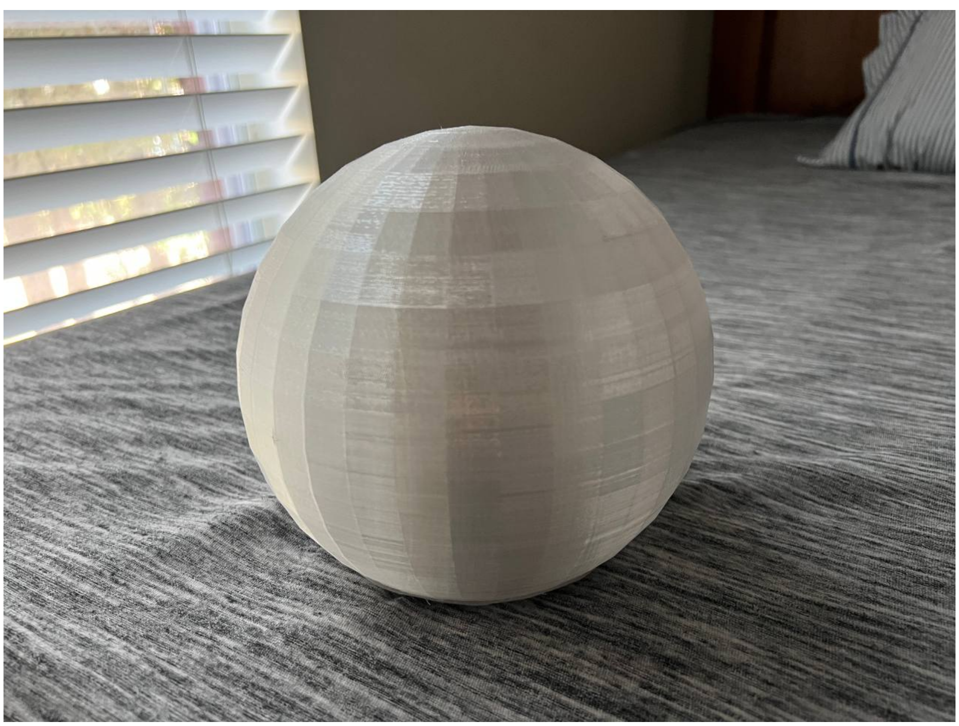
- **2.2 Select needed components:** Lead by Hector Carrera and completed on 05/01/22
- **2.3 Determine power requirements of the device:** Lead by Jackson Clark and completed on 11/04/2022
- **2.4 Design and build the circuitry:** Lead by Christopher McLoughlin and completed on 11/07/22
- **2.5 Select and implement rechargeable batteries:** Lead by Hector Carrera and completed by 10/28/22

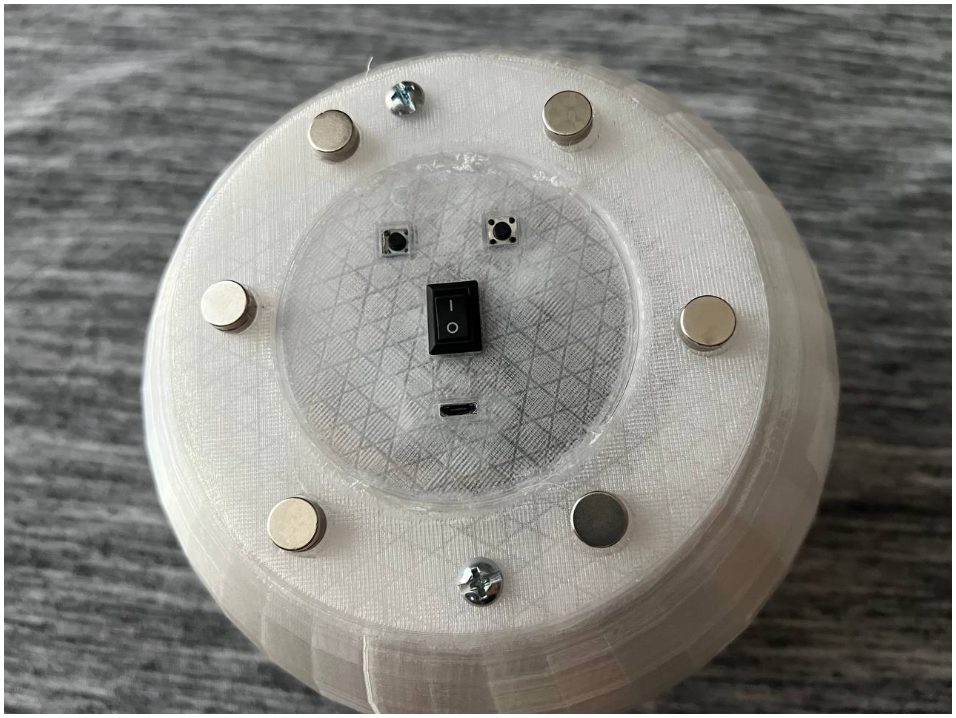
- **Embedded**

  Lead Engineer: Christopher Andrew (All subtasks lead by Christopher Andrew)
  - **3.1 Code LED control:** Completed on 09/30/22
  - **3.2 Implement USB communication:** Completed on 11/11/22
  - **3.3 I/O design:** Completed on 9/30/22
  - **3.4 Implement a windowside USB:** Completed on 11/11/22

Deliverable Results - Images

Below are images of the finalized deliverable for the project!





Figures 3 a-c: Completed Project Images

Features and Specifications

- **Size:** 9 x 9 x 6”
- **Weight:** 16 oz.
- **LED specifications:** 100-1000 lux, 5 hour battery life, 2400k - 6500k Color Temperature Range
- **Input source:** 5 V
- **Customizable design:** The design of the structure allows the user to install the component in any configuration as they see fit and the open source software design would allow the user to upload a custom firmware for the microcontroller
- **USB-A for charging:** USB-A port allows for easy recharging
- **Color temperature modification and dimming:** Device can cycle through the color temperature range and brightness to suit the user’s needs
- **Mounting functionality:** The device will have a magnetic base allowing it to mount on any ferromagnetic surface
- **Push button Controls:** Three push buttons will be located on the base of the device

Engineering Specifications

Here is the finalized schematic for the lighting system…

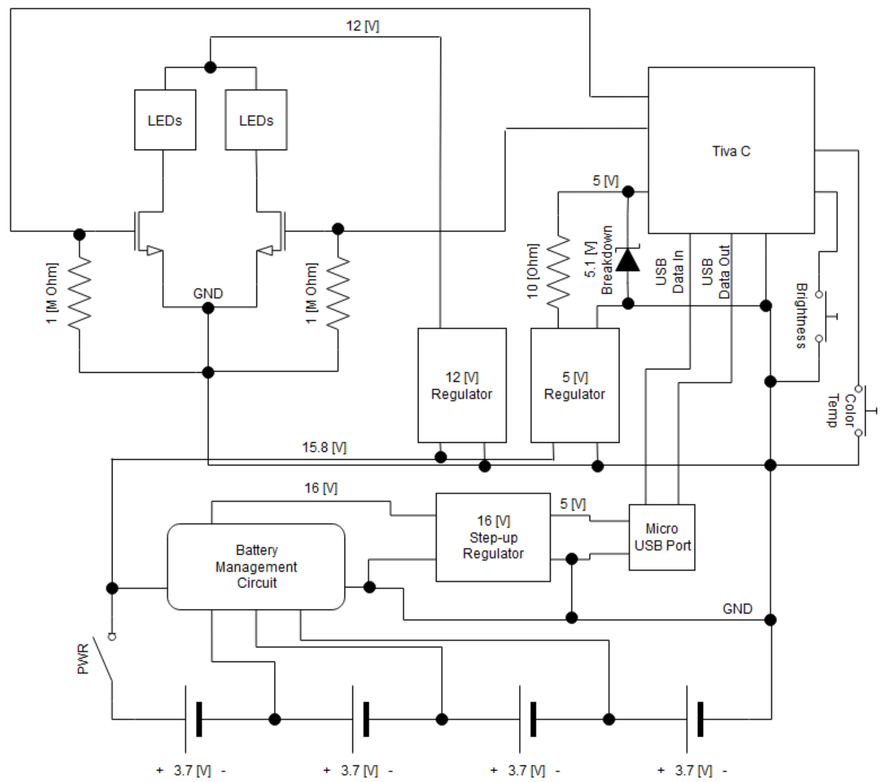


Figure 4. Schematic for the lighting system

In this schematic, we can see that the main objects of note are the switching regulators at 5 and 12 [V] logic, the step-up regulator to 16 [V] and the BMS. The Zener diode added at 5.1 [V] breakdown has been added as a safety mitigation for voltage spikes inside the TIVA-C, which can be as a result of the microUSB port and subsequent connections. The LEDs are wired in a current mirror configuration with N-MOSFETs to provide the sufficient gain and brightness required from the 12 [V] regulator to sustain the brightness. The BMS, additionally, provides additional safety features for the batteries when charging, as well as when delivering a clean signal to the circuit.

Test Plan

Below is our test plan for each of the target task numbers.

Table 1. Consolidated Test Plan with Task Numbers

Task #	Functionality	Testing Parameters	Verification Method	Target Values
1.1: Sphere	Rigidity, durability, transparency	Size, shape, durability	Testing durability by exposing it to different environments	Can withstand at least 5 lb. of force and a drop from 5 ft.
2.3: Power	Safety, usage	Usage of [V], [A], etc.	Testing usage of power of LEDs, PCB, etc. using a multimeter	Low Power profile (less than 3W discharge across)
2.4: Circuitry	Safety, usage, efficiency	Usage of [V], [A], etc.	Testing the rigidity and efficiency of circuitry.	Testing the resistance between components and making design more efficient. (20%)
2.5: Battery	Efficiency, durability	[mAh], [Wh] capacity and usage of power in [W]	Testing the endurance of the battery in many scenarios.	Ensuring 5 [h] runtime.
3.1: LED Control	Brightness, color temperature, efficiency	[K] and [lx] for brightness and color temperature	Testing the LEDs come with proper parameters.	Ensuring efficiency and coverage in brightness and spectrum (2500K-6500K) and 500 [lx]

We followed this test plan. We also validated the specifications using this test plan, particularly by using a colorimeter and a brightness meter to determine that the brightness and color temperature specifications are met. Additionally, we also tested power draw with a multimeter and using electrical analysis, as required, and as specified above.

Flowchart

Here is the flow chart which shows the operation logic across the device in a simplified fashion…

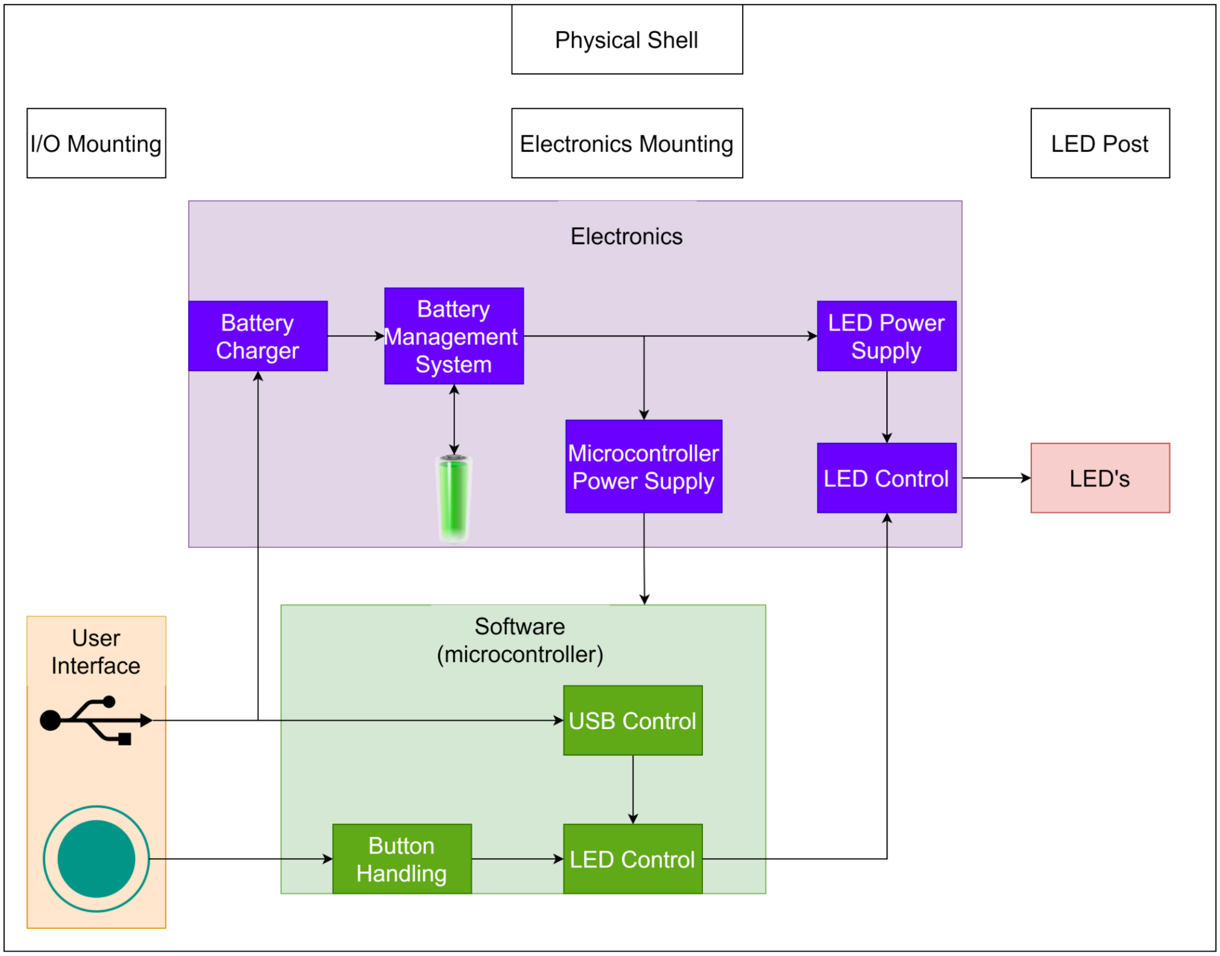


Figure 5. Flowchart of logic of the lighting system

Risk Management

Below is the risk management matrix, which depicts the risks in conjunction with their related consequences and probabilities.

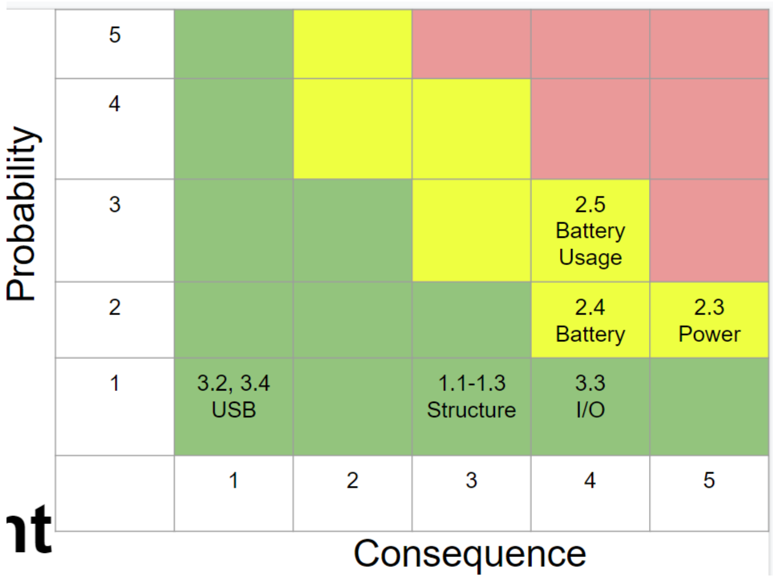


Figure 3. Risk Management Matrix

We can see that the highest risk is still for Task 2.5, which is the battery usage, as there are many variables which can affect the power draw and subsequent battery usage of the device. But the risk has been reduced due to additional testing.

Risk Severity

We have determined the following tasks to yield the following severities and points for concern…

Table 2. Severities for Risks

Task Number	Task Name	Severity
2.5	Battery Usage	12
2.3	Electrical Power	10
2.4	Electrical Battery	8
3.3	Embedded I/O	4
1.1-1.3	Structure	3
3.2, 3.4	Embedded USB	1

By multiplying the consequence and risk intersections, we can determine the severity points above.

Mitigation Plan

Task 2.5: Battery Usage

The risks associated with the use of Lithium-ion batteries can include combustion, and/or damage to the electrical circuits. The risk of battery combustion is mitigated by purchasing legitimate 18650 batteries from a reputable source and installing the proper charging protection circuitry. We can reduce the risk of damaging the device's circuit by installing a diode to ensure the batteries are in the proper polarity.

Task 2.3: Electrical Power

Our device has two step-down switching voltage regulators. This type of voltage regulator is associated with large output current, high signal noise, and some output voltage ripple. These conditions can lead to component failure. We plan to mitigate the risk by including zener diodes to protect against voltage spikes and decoupling capacitors to reduce signal noise.

Task 2.4: Electrical Battery

Poor circuit power management can lead to suboptimal device performance, and/or shorter device runtime. We can improve the device performance and runtime by optimizing the active loads and eliminating any parasitic loads.

Task 3.3: Embedded I/O

The risks associated with the microprocessors I/O can include pin failure, button failure, and improper input readings. The bulk of these risks can be mitigated by simply editing the software and making the appropriate changes to the physical connections. However, in the risk of button failure, we can easily replace the faulty button.

Tasks 1.1-1.3: Structure

Risks associated with the structure can be mitigated by strength testing our current design. In the case of structure failure, we can easily redesign and print a new structure.

Tasks 3.2 & 3.4: Embedded USB

Due to the lack of protection on the microprocessor's data lines, there is a non-zero chance that damage could occur. In this unlikely scenario, we can use alternative forms to communicate with the microprocessor such as UART, I2C, CAN, or USB via the debug controller.

Results

Final Schedule

The final schedule can be observed by the Gantt chart provided above. All deadlines were met at the same rate as we expected, with some delays in earlier versions of the Gantt chart which prompted modifications.

Accomplishments

We developed an elegant and reconfigurable solution for lighting and for use in outer space. As one can see above in the deliverables images above, the orb is fully featured with USB charging, LEDs, and meets all engineering specifications.

Setbacks

During assembly of the LED controls it was discovered that our 5 [V] buck converter generates large voltage spikes during start up. These voltage spikes resulted in the destruction of our TIVA-C microcontroller. This was due to the fact that although the TIVA-C has some over voltage protection in the form of a 5 Volt to 3.3 Volt regulator to supply power for the device, the external power supply is also used for USB VBUS detection and is wired directly into the microcontroller with no protection present. This issue was solved by adding a zener diode and resistor to the output of the regulator to manage voltage spikes above the 5 [V] rating of the TIVA-C power supply pin.

During testing of the battery charging system it was discovered that the battery charging system could draw far more current than the boost converter claimed to be limited to resulting in damage to a USB port. This issue was fixed by implementing a circuit to limit both the max voltage and current that can be supplied through the USB port of the device.

Finally we needed to redesign the LED post. Our original design had the control electronics mounted at the bottom of the spike and we found there was not enough room. Our new design consisted of a hollow cylinder with the electronics stored within and the LEDs wrapped around the outside.

Summary and Lessons Learned

As mentioned earlier, we believe we created a minimal, robust yet functional and reconfigurable lighting system for crew in outer space.

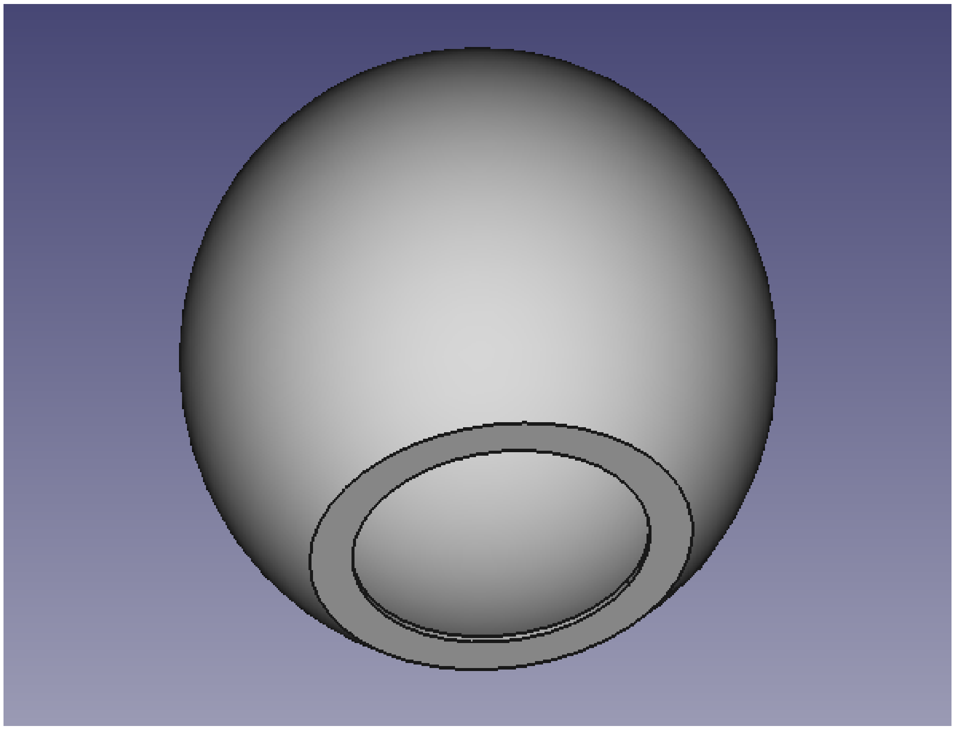
Lessons learned for this project include…

- The intricacies of the engineering design process
  - The need for more organized procedures at the beginning of the semester
  - The need for proper task delegation and organization
    - Mitigated as the semester went on. Learned a lot about task delegation and the importance of keeping a schedule.
- Handling setbacks
  - Using troubleshooting time more wisely
    - Voltage spiking protection circuitry
    - 3D printing challenges
    - USB communications and controls
  - Contemplating the improbable
    - Thinking ahead of possible design considerations
  - Design optimizations
    - Improving the design

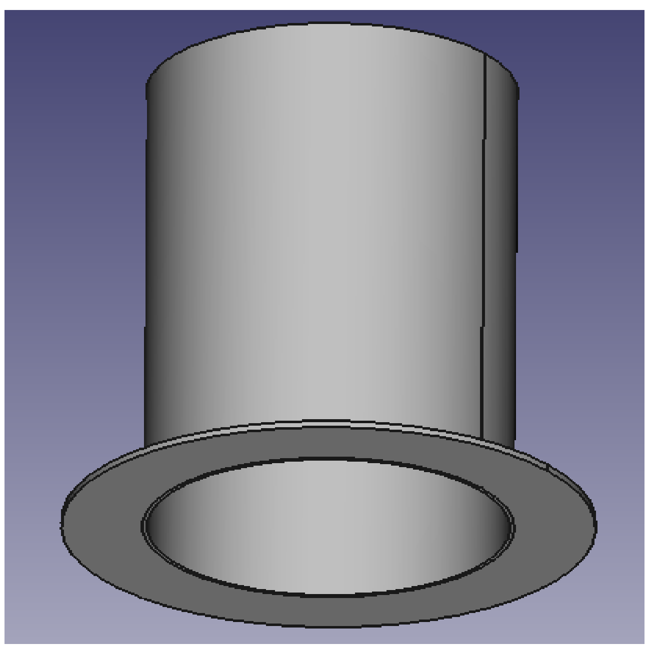
All these experiences were fruitful for our engineering careers, and we learned a lot.

Appendix

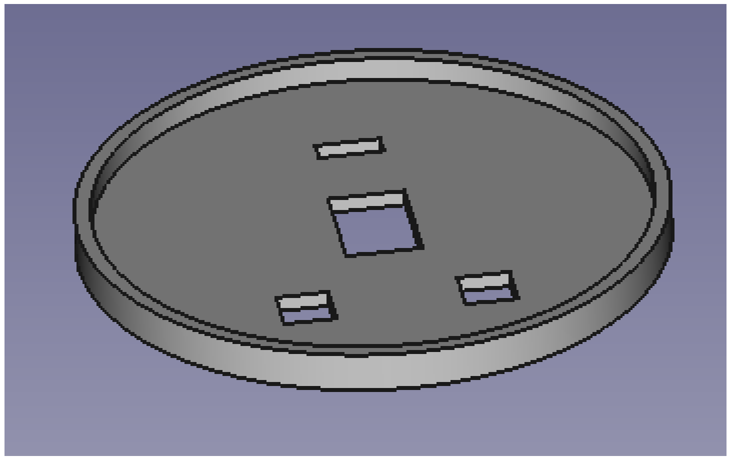
CAD drawings of each structural component



CAD drawing for the sphere.



CAD drawing for the mounting post.



CAD drawing for the bottom plate with ports for buttons, a switch and a micro USB port.

Parts used and quantity

Part	Quantity
BS270 NMOS Transistor	2
Warm LED strip	2.5 [ft]
Cool LED strip	2.5 [ft]
Step down switching regulator	2
Step up switching regulator	1
TI TIVA C	1
Micro USB port	1
4S BMS module	1
18650 lithium ion battery	4
18650 battery holder	2
10 [Ω] resistor	1
5.1 [V] Zenor diode	1
1 [MΩ] resistor	1
Push button	2
On/off switch	1
Neodymium magnet	6

10-24x1 machine screw	2

References

[1] W. Walker, S. Yayathi, J. Shaw, H. Ardebili, Eds., “Thermo-electrochemical evaluation of lithium-ion batteries for space applications,” in *Journal of Power Sources*, Dec 2015. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0378775315302081

[2] C. Réti, M. Casetta, S. Duquesne, S. Bourbigot, R. Delobel, Eds., “Flammability properties of intumescent PLA including starch and lignin,” in *Polymers for Advanced Technologies*, Jun 2008. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/pat.1130

[3] “Battery Management Systems Ensure Safety and Reliability.” aved.com. https://aved.com/battery-management-systems-ensure-safety-and-reliability/ (accessed Dec 12, 2022).

[4] Iman Dianat, Ali Sedghi, Javad Bagherzade, Mohammad Asghari Jafarabadi, Alex W. Stedmon, Eds., “Objective and subjective assessments of lighting in a hospital setting: implications for health, safety and performance,” in *Ergonomics*, Jul 2013. [Online]. Available: https://www.tandfonline.com/doi/abs/10.1080/00140139.2013.820845