Hyperspectral Imaging Lighting System
InterEGR 170
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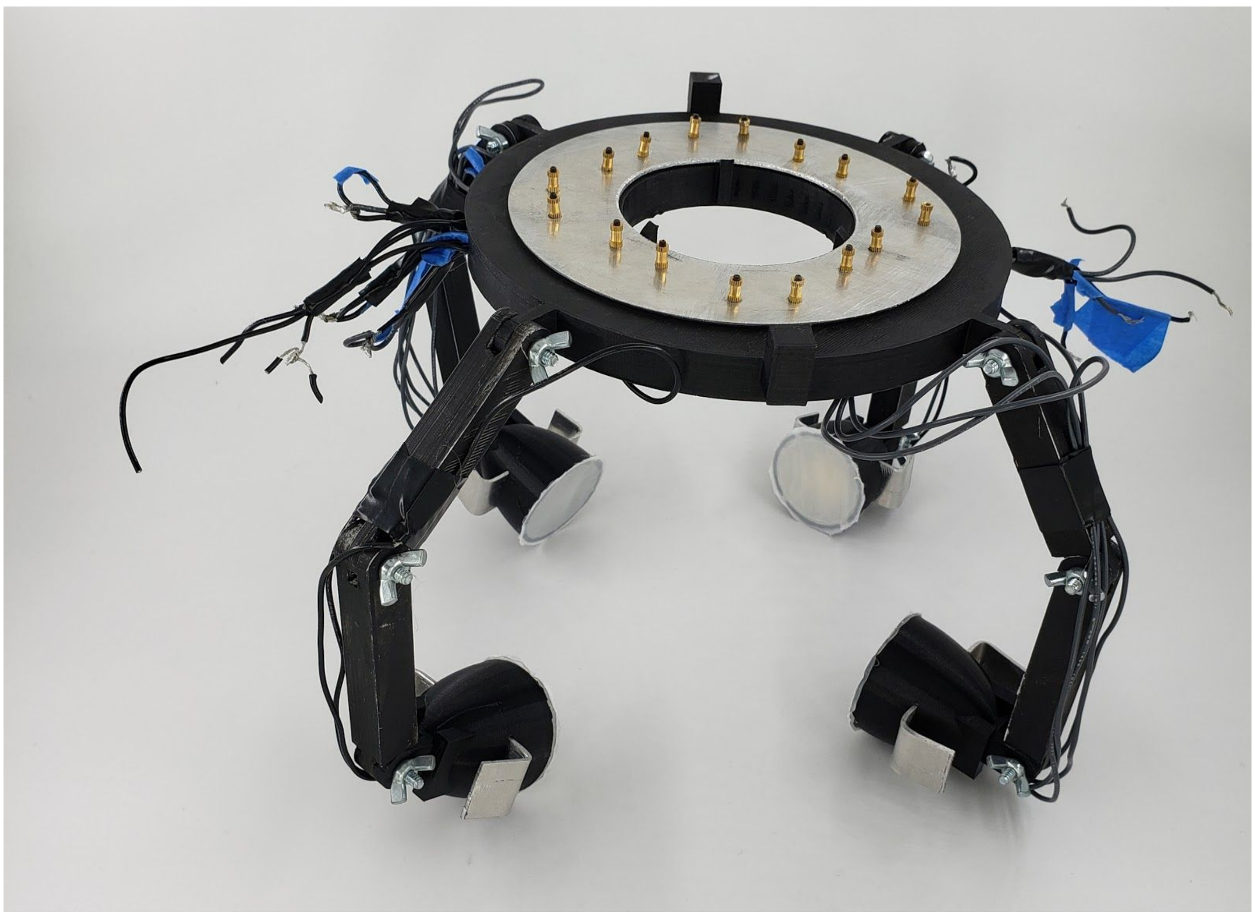

Abstract

The engineering team was asked by Max Lien from Professor Townsend's Environmental Spectroscopy Lab to improve their current lighting system for the HyperScanner, a hyperspectral imaging system. The new lighting system needed to be brighter, more even, output red, green, blue, and white light, and not melt light housings or burn plant samples. The proposed solution was a Ring Lighting system that integrated six RGB and six white 10W LEDs into a custom-made ring housing and ellipsoidal housings that are connected by four sets of adjustable arms. This design can emit all four colors of light and output high intensity photons appropriate for hyperspectral imaging while generating less heat. With the future in mind, this design's adjustable arms allow for the system to adapt to the subjects it is lighting and keep the illumination even. Additionally, most of the parts were 3D printed making them affordable and scalable for future systems. The 10W LEDs could also be swapped for different power LEDs to either lower the cost or adapt the system to new uses. In total, the system that was designed cost about $130 to produce making it easily accessible to labs on a budget.

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Introduction

Problem Statement

Max Lien from Professor Townsend's Environmental Spectroscopy Lab created a hyperspectral imaging scanner named the HyperScanner in order to perform hyperspectral imaging on plant samples. The current HyperScanner lighting system casts shadows across the plant samples, especially on leaves lower on the sample. In addition, there is a potential to burn the plant samples and melt the lights' housing. The current system illuminates a small area and can output one color colors of light. A new system must be made that reduces shadows, does not burn plant samples or melt housing, and outputs multiple colors of light.

Client's Needs Research

Max Lien's objective with Professor Townsend's Laboratory is to validate hyperspectral imaging's ability to capture information that is currently being captured through point spectroscopy [1]. This validation would yield great returns because hyperspectral imaging is a fairly quick and non-invasive process, unlike point spectroscopy. This means that plant specimens could be analyzed in real time to determine the health of the plant before it shows signs of distress to the human eye. In turn, farmers could take preventative action to restore the health of their crops before it is too late. Such action would provide a more stable production of food for the planet and cut down on costs from crops lost to factors like drought and salt stress. Additionally, hyperspectral imaging could be used to monitor large areas of non-agricultural flora like forests to aid in the preservation of Earth's natural resources.

Design Research

The lighting system that the HyperScanner previously utilized (Figure 1.1) was used as an inspiration and starting point for the final, improved lighting design. This previous design used halogen bulbs that burned plant samples and melted the lamps housings. LEDs were chosen to eliminate these heat issues because they operate at lower temperatures and can illuminate large areas [2]. To further reduce the risk of melting the housings, it was determined that a heatsink should be made which would also serve as a mounting point for the LEDs. The most suitable material for this heatsink was aluminum since it conducts heat well and is lightweight compared to other options [3]. In addition, LEDs come in various colors and wavelengths which, as previously mentioned, is desired by the client. Initially, both LED chips, bulbs, and lightstrips were under consideration, but after further research the LED chips were deemed most suitable for this lighting system. LED chips were chosen due to their size and ability to have customizable wiring and circuits, allowing for the wires to discreetly run along the housing system and not interfere with scans.

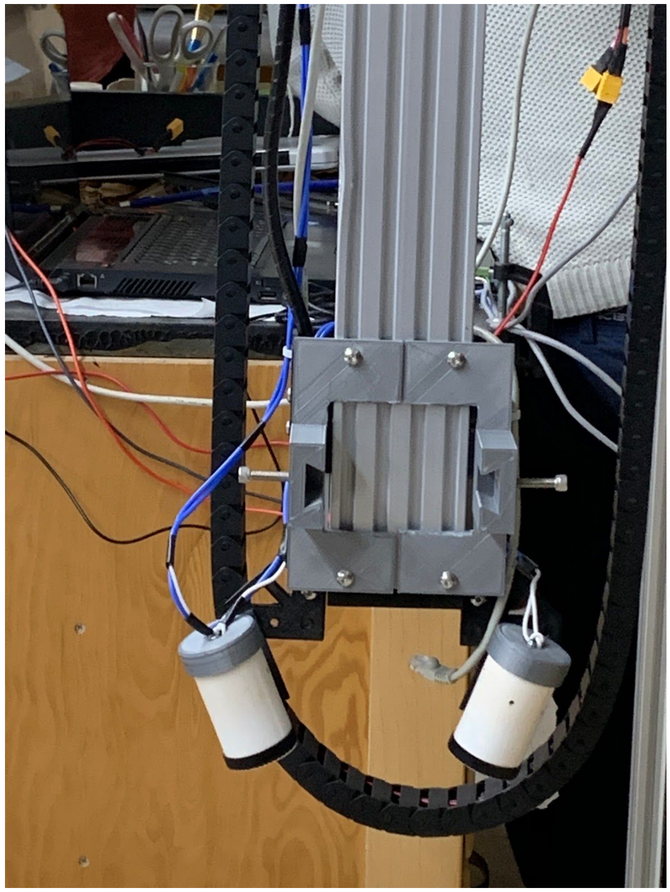

Figure 1.1 Previous Lighting System. Front view of the lighting system that was intended to be upgraded.

Due to the multiple LEDs that the housing system will be in contact with, it was essential to make sure that the housing was made up of a durable material that can also withstand the temperature of the lights. It was known from the start of the project that 3D printing was the best option because of how user friendly and affordable it is. The two prominent options for material were PLA and ABS. ABS may have a slightly higher melting point than PLA, but PLA has greater durability, lower heat conductivity, and it is more easily handled by 3D printers which made it the optimal choice [4]-[6]. A variant of PLA, tough PLA, was used for the mounting joints since it is the same price but has a higher resistance to stress [7]. Another key feature that needed to be present was an even illumination of the subjects. In order to make the PLA arm housings disperse light evenly, an ellipsoidal shape for the housings was optimal because ellipses optimize uniformity of light through their reflective properties [8].

Another aspect of the improved lighting system that required extensive research was the coding of the Arduino. Most of the background information on Arduino and how to code one was found through the official Arduino website [9]. Since the improved lighting system utilizes multiple LEDs with multiple colors that must be controlled separately, a code that could turn on and off individual sets of LEDs with a push button was necessary. Such a code was found on the Arduino company's website and turns on built-in LEDs when the corresponding button is pressed [9]. Lastly, it was found that power relays would be needed to have the Arduino control lights that require more five volts [10].

Existing Designs:

Previously, the lighting system design consisted of two 20 watt, halogen lights powered by a 300 W DC power supply capable of outputting five amps and 60 volts [1]. These halogens were enclosed in cylindrical, PVC housings that attached to the actuator arm. The housings could have their height on the actuator arm adjusted by adjusting the mounting screws, and the angle of the lights could be changed by pivoting the housings on their mounts. The lights were mounted parallel to the camera's scan line to increase evenness of lighting on the subject [1] (Figure 1.1).

Design Specifications:

From Max's description of problems with the current lighting system, a list was created with the requirements for the new design. These needs included brighter lights, modularity, illumination of one square foot, white, red, green, and blue light options, low weight, even lighting to minimize noise in the hyperspectral images, minimal shadows, and not burning plant subjects [11] (Appendix A).

Preliminary Designs:

Using the client's design needs and the team's design research, three designs were created.

Plate Lighting Concept

The Plate Light concept consisted of a two 3D printed plates with four inch diameters and four LEDs mounted on each plate. These plates would be mounted to a four inch arm that connects to the actuator arm. These arms would be mounted on a pivot point to allow the arms to be adjusted to different needs. This design excelled in its ability to illuminate subjects evenly because it had eight powerful LEDs and the ability to change its focus. However, the device did have shortcomings. It would be unable to illuminate the subject from directly above because its mounting was parallel to the arm and it could not be centered above the subject. The Plate Light concept also had the flaw of not being able to effectively illuminate the front and the back of the subject which would create shadows around the subject (Figure 2.1-2.2).

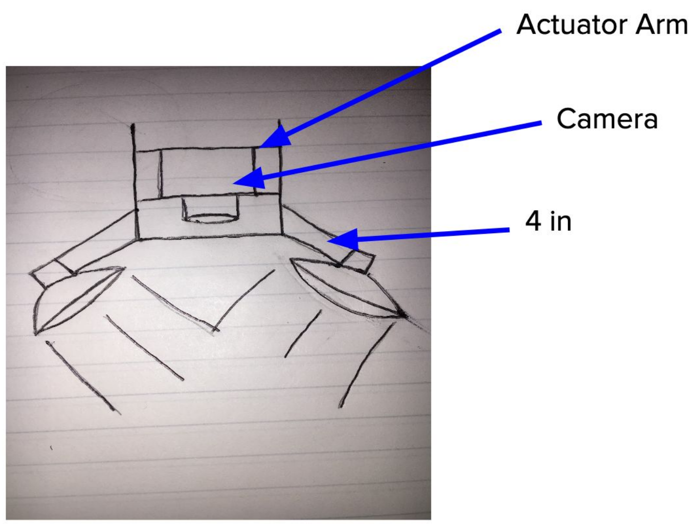

Figure 2.1 Plate light system design. Front view of plate design attached to arms which are on pivot joints attached to the actuator arm.

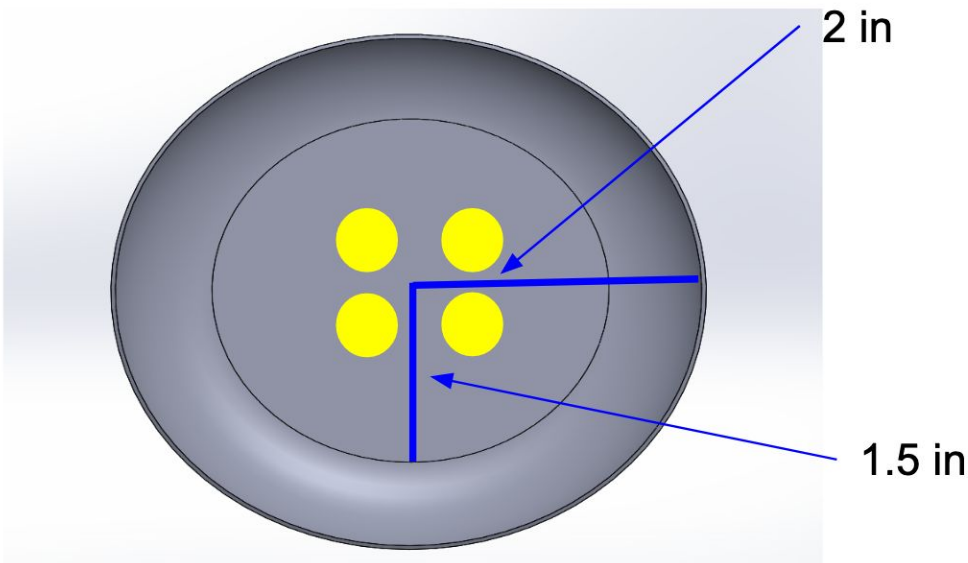

Figure 2.2 Plate light design. This design incorporates the Plate Light structure above with four LEDs represented by yellow dots embedded into the plate's surface.

Ring Light Concept

The Ring Light concept consisted of two main elements, the ring and four adjustable arms. The ring was suspended from the actuator arm through a custom joint system that slid into the 20-80 rail. 12 LEDs would be embedded in a 3D printed ring housing. This Ring Light housing had four mounting points about the ring's perimeter so a 3D printed jointed arm system could be attached. The end of these arms would have conical shaped housings to focus the light in a singular direction.

The ring light had many advantages from its complex design. It could illuminate the subject from above with the ring and on all sides with the adjustable arms. The adjustability of the arms allows for even lighting to be achieved for bigger potential subjects. Despite these advantages, the moving parts of the device introduced possible structural flaws because these parts introduce another weak point where the design can break. Additionally, this design has a larger profile from the arms extending from the ring. This larger profile could create a greater risk of bumping the lighting system while manipulating samples and bumping the lighting system into samples being scanned (Figure 2.3).

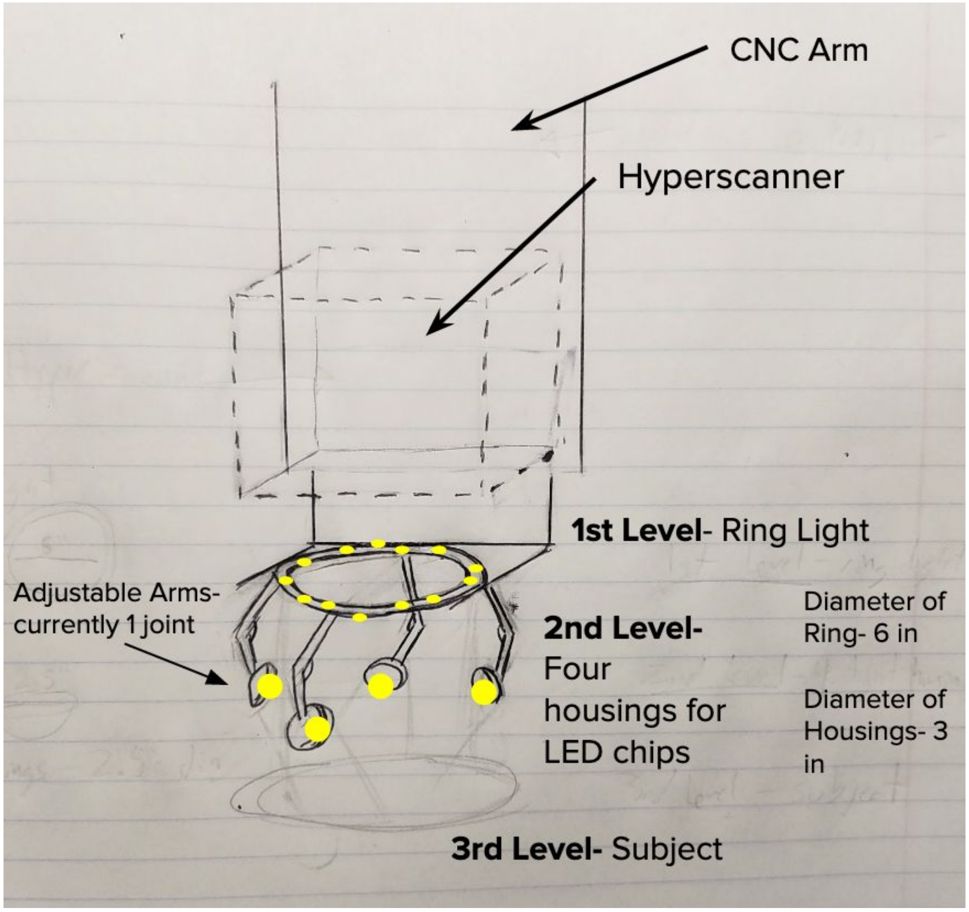

Figure 2.3. Ring Light Preliminary design drawing. The ring light is comprised of two different levels of lights. The first is the ring with the second being the arms coming of the ring with housings. The yellow dots represent the 10W LED chip placement in the design.

Softbox Lighting Concept

The Softbox Lighting concept was comprised of a flat 6x6 inch square with folded lips that follow a quarter circle with a one inch radius. The Softbox Lighting housing was lined with LED strips instead of LED chips to illuminate subjects from above. LED strips would also be easier to integrate with an Arduino which was a huge advantage of this design because it cuts down on wiring cost and time and would make production faster. Additionally, the strips have many more LEDs to produce more even, direct lighting. Despite these advantages, this design would be dimmer because LED strips consume less power than LED chips. Another potential issue was its ability to only project the light in a single way with no adjustability which could cause issues with shadows and illuminating more complicated plants (Figure 2.4-2.5).

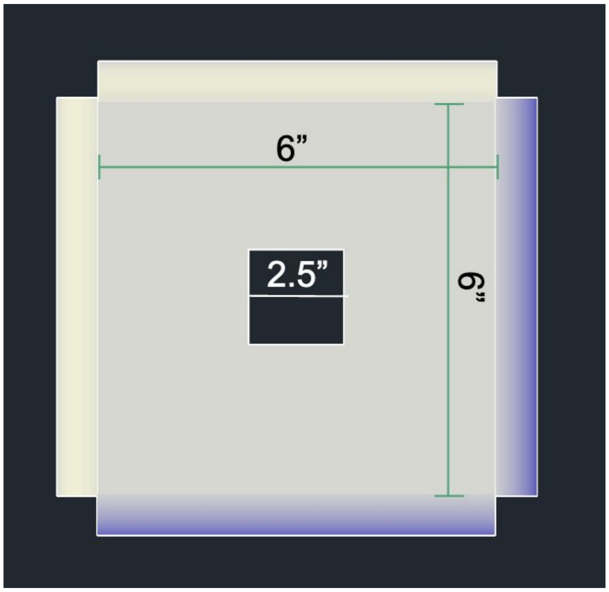

Figure 2.4 Top view of soft box design. This design uses a square as its base point with four 1” offset lips that are curled down one inch off of the top square.

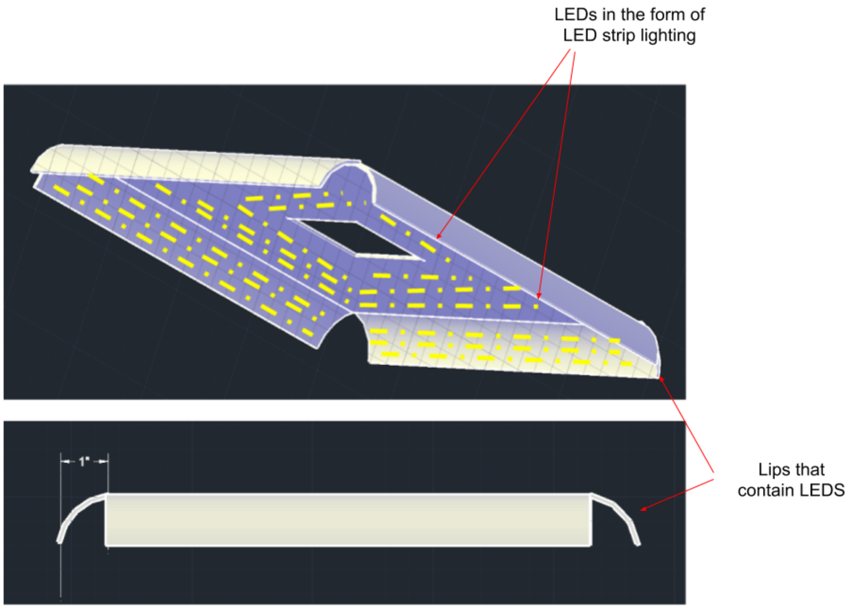

Figure 2.5 Side and offset views of the softbox design. This design utlizisez led stips which are shwin by the yellow dots and rectangles that are placed on the lips and bottom of the softboxin order to illuminate the object below.

Preliminary Design Evaluation

In order to determine the best design to move forward with from the three preliminary designs, a design matrix was created to compare six characteristics of the designs. These six characteristics were chosen based on team research and client specifications. The six characteristics chosen were even lighting, area covered, durability, weight, bulkiness, and ease of mounting. Even lighting referred to how evenly the subject is illuminated, area covered considered how large of an area the design could illuminate, durability considered how well the design would handle regular use and the occasional misuse, weight examined how heavy the design was, bulkiness considered how much space the design would take up, and ease of mounting considered how easily the design could be mounted to the current CNC machine setup.

These six areas were all assigned weightings based on conclusions drawn from team research and design specifications. Even lighting and area covered were weighted most heavily because these were the vital areas where improvements needed to be made. The rest of the areas had similar weightings except for the weight which had lower weighting because the weight threshold was high at seven kilograms. The Ring Lighting received highest marks for even lighting because it allowed for a versatile illumination area with the adjustable arms. Plate Lighting excelled in weight and ease of mounting with 7.17 and 8.00 points, respectively, because it was lightweight and very similar to the current system. Lastly, Softbox Lighting received the best marks for bulkiness at 4.67 points because it had a streamlined design. In total, Ring Lighting received a score of 77.51 out of 100, Plate Lighting received a 74.88, and Softbox Lighting received 68.22. In turn, Ring Lighting was the preferred final design (Table 3.1).

		Ring Lighting		Plate Lighting		Softbox Lighting	
Criteria	**Weight**	**Score (max 10)**	**Weighted Score**	**Score (max 10)**	**Weighted Score**	**Score (max 10)**	**Weighted Score**
Even Lighting	28	10.00	28.00	8.00	22.40	7.00	19.60
Area Covered	28	8.00	22.40	8.00	22.40	8.00	22.40
Durability	16	6.00	9.60	6.83	10.93	6.83	10.93
Weight	6	6.00	3.60	7.17	4.30	5.00	3.00
Bulkiness	11	4.83	5.31	5.5	6.05	4.67	5.14
Base of Mounting	11	7.83	8.60	8.00	8.80	6.50	7.15
Sum	100	Sum	**77.51**	Sum	**74.88**	Sum	**68.22**

Table 3.1 Decision Matrix. This table shows the design criteria used to evaluate the designs along with the weight assigned to each Category. The scores given by the group are also shown with max scores of different categories highlighted in yellow.

Preliminary Final Design

All of the preliminary designs and the design matrix were presented to the client. The client was in agreement that the Ring Lighting concept seemed to be the best option. However, they suggested designing the mounting joints directly from the mounting arm SolidWorks model and looking into the reflective properties of ellipsoids for the arm housings. Other than the change of making the conical shaped housings ellipsoidal, the preliminary final design was identical to the previously described Ring Lighting concept (Figure 4.1-4.8).

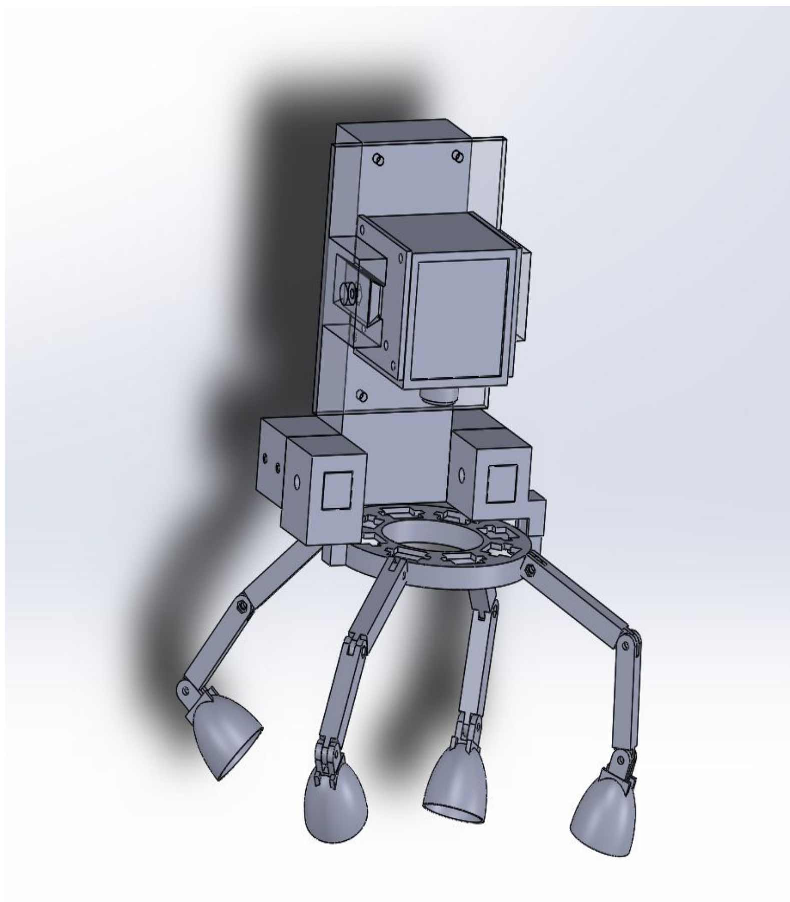

Figure 4.1 Full view of preliminary final design. This is the full assembly of the ring light mounted onto the actuator arm with the arms pointed down. All of the dimensions of these parts are detailed in Figures 4.3-4.7.

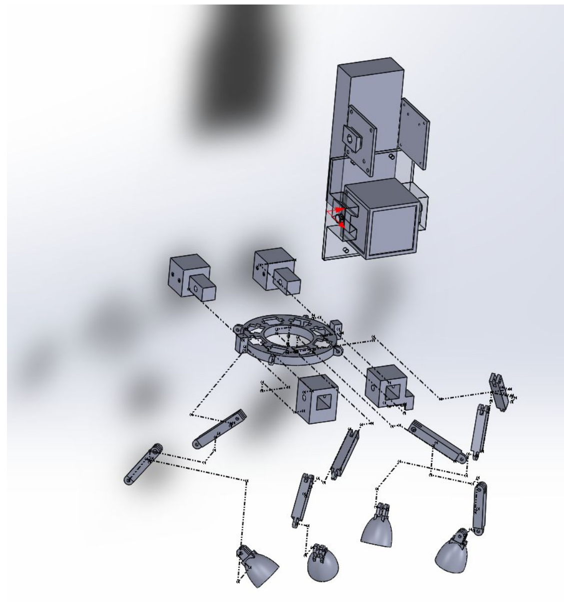

Figure 4.2 Exploded view of preliminary final lighting system design. This is the view with all parts taken away from one another with lines showing connection parts of all the various parts. All of the dimensions of these parts are detailed in Figures 4.3-4.7.

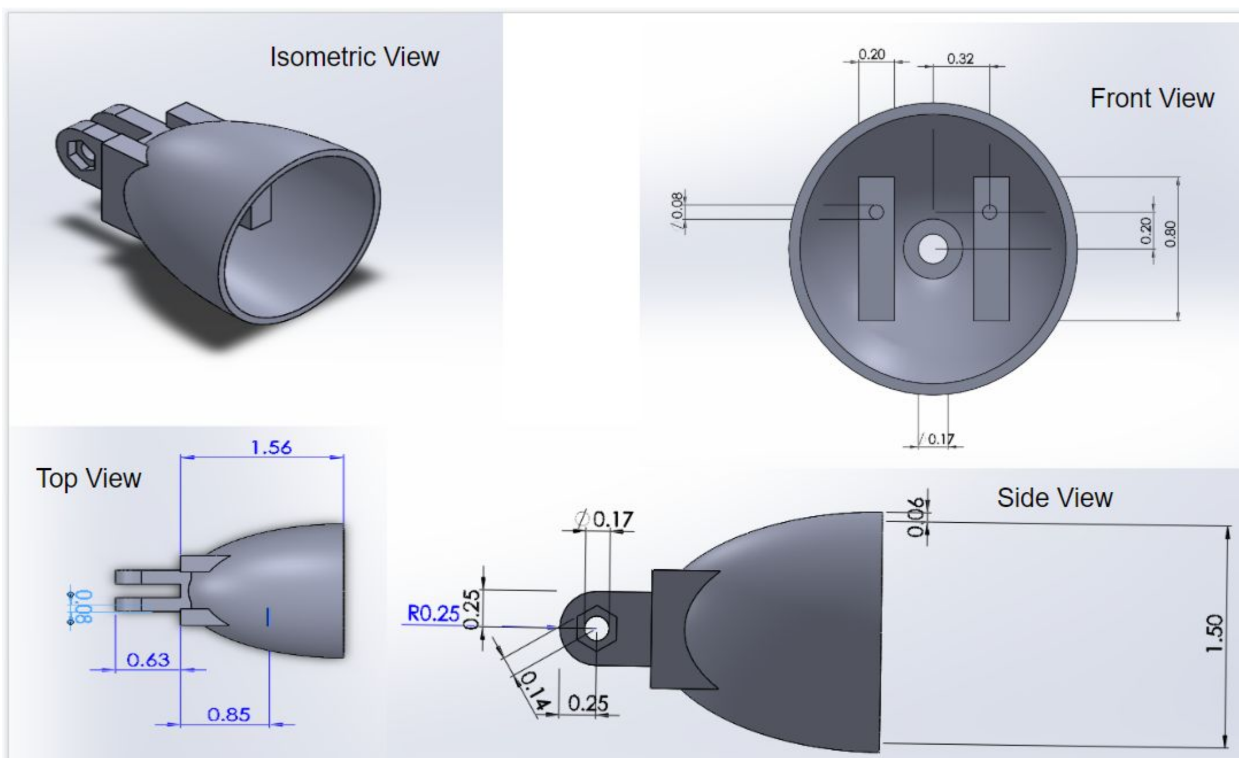

Figure 4.3 Various view of preliminary LED light housing. These housings are attached to the arm joints, The LEDs are attached inside the housing along with the aluminum heatsink.

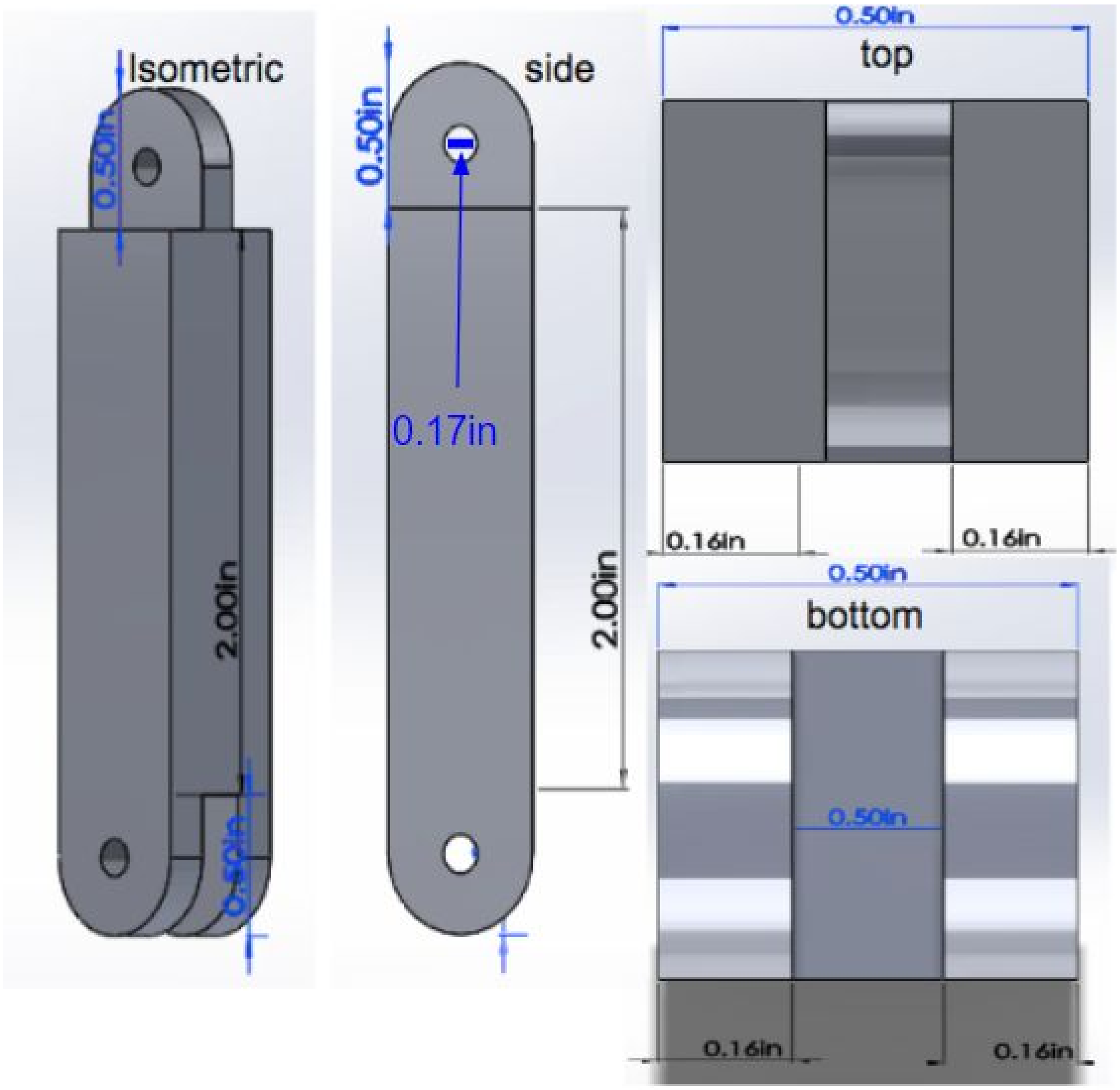

Figure 4.4 Various views of preliminary adjustable arm digit. These arm digits are attached to each other, the ring housings, and the arm housings with bolts and wing nuts.

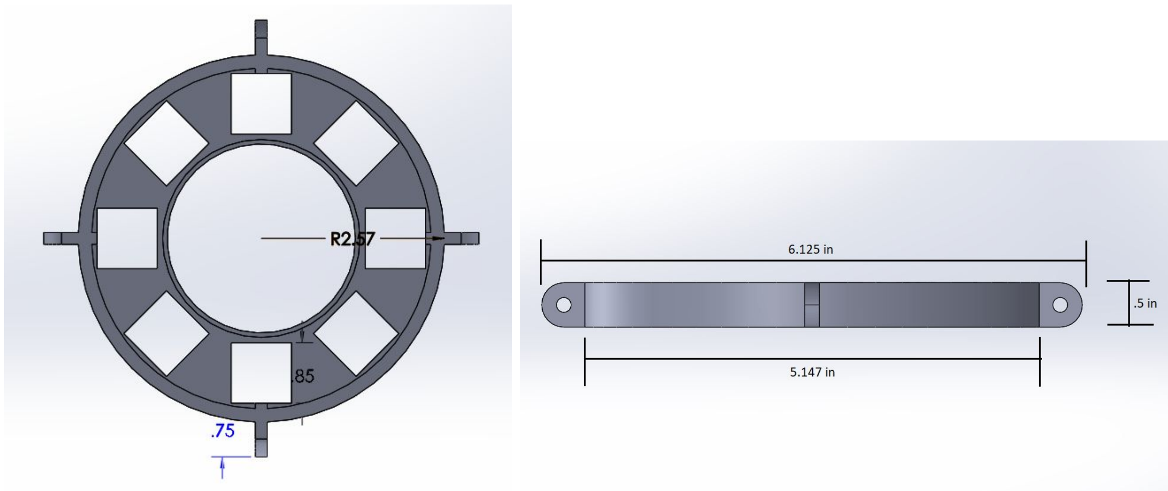

Figure 4.5 Various views of preliminary ring housing. These images include the top and side views of the preliminary ring housings. The LEDs and heatsink fit into the square holes on the top and the arms were attached in the joints on the sides.

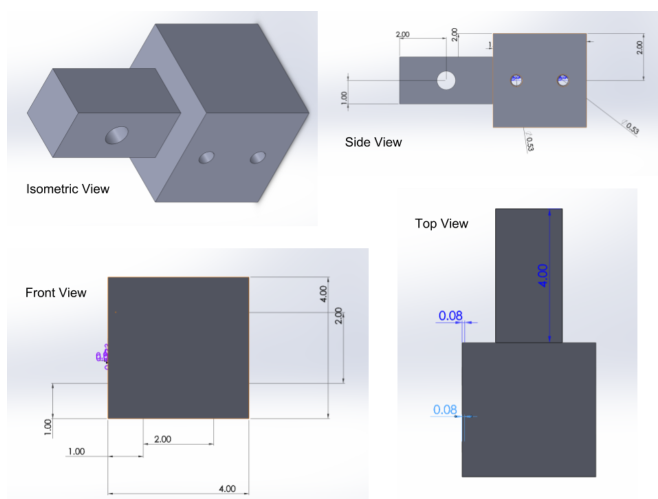

Figure 4.6 Various views of preliminary male mounting joint. This is the male joint which has holes in the side where are used as mounting points to the actuator arm. The hole in the middle is the point for the pin to slide in to secure the mount to the female part.

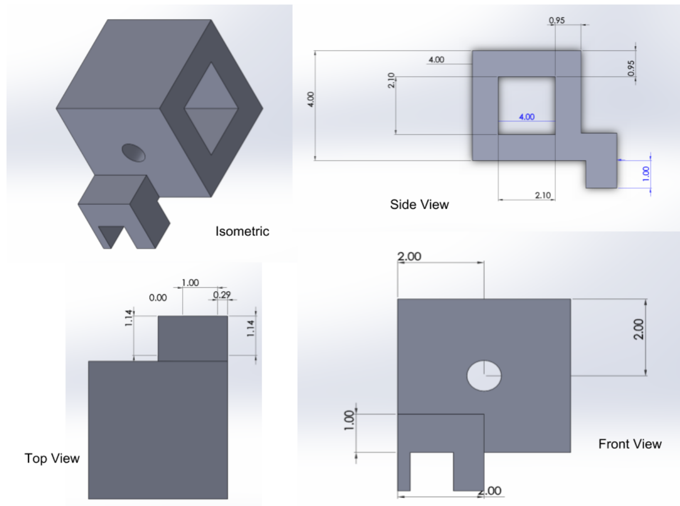

Figure 4.7 Various views of preliminary right female mounting joint. The female part slides over the male rail to become flush with it. The holes then line up where a pin can be inserted to hold the joints together. The ring then connects to the lower bracket by sliding in.

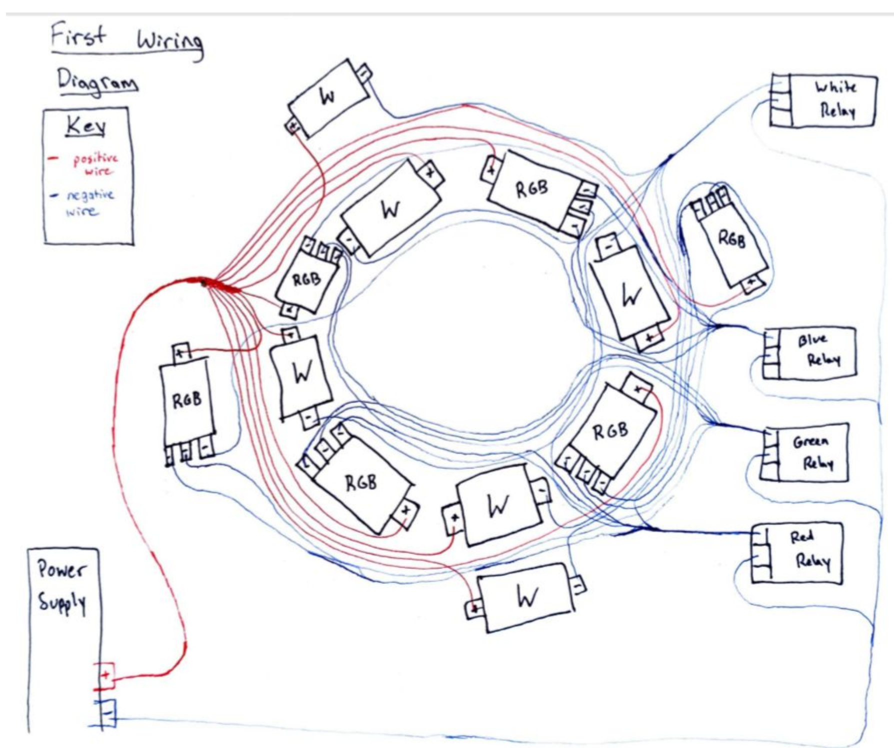

Figure 4.8 Preliminary wiring diagram of the LEDs. The preliminary wiring plan for the LEDs was to wire all of the LEDs in parallel.

Fabrication

After deciding to move forward with the Ring Lighting design through consultation of the design matrix, the team compiled a list of required materials and either ordered or acquired them from the client. Once the materials were acquired the team began fabrication of the prototype.

Materials

The Ring Lighting design used a handful of materials. The major component of the design was PLA and tough PLA because all of the housings, arms, and joints were 3D printed. (tough) PLA was chosen over ABS plastic because it has a higher durability, lower heat conductivity, and works better with 3D printers than ABS [5]-[6]. In addition, six RGB and six white 10 watt LED chips were used for the lighting source because they produce less heat and more light per unit of power than halogen lamps. An Arduino attached to a breadboard with various wires, resistors, and buttons was needed to control the LEDs. Arduino microprocessors can directly power lights that use up to five volts. The LED chips that were used use anywhere from 8-11 volts, so a series of relays was needed so the LED chips could be properly powered.

Because the LED chips consume more power, a large circular heatsink for the ring housing and individual heatsinks for the arm housings were machined out of a 1/16th inch aluminum sheet. Thermal heat paste was used to insulate the connection between the LEDs and heatsinks. Various hardware including threaded brass knurlings was used to attach the LED chips to heatsinks and housings, the arms together, and the mounting joints to the CNC arm. For the finishing touches of the arm housings, foil tape was attached to the inside to reflect the light outward and diffusion cloth was stretched over the opening to produce an even light. The adjustable arms required a coat of matte black spray paint to reduce the potential of reflecting light (Table 5.1-5.2) (Appendix B).

Development Costs

Material	Price	Source	Quantity	Subtotal
PLA	$0.06/gram	Makerspace	527 grams	$35.25
Arduino components-Wires, resistors, relays, buttons	$3.50	Max and Makerspace	Varies	$3.50
10 W LED Chips (RGB)	$6.28/chip	Amazon	1	$6.28
10 W LED Chips (White)	$6.28/chip	Amazon	8	$50.24
Total				**$95.27**

Table 5.1 Table of Development Materials. A cost breakdown of all of the materials used in the development of the final design.

Final Prototype Costs

Material	Price	Source	Quantity	Subtotal
Tough PLA/PLA	$0.06/gram	Makerspace	364 grams	$21.85
Arduino	Free	Max	1	Free
Breadboard	Free	Max	1	Free
Diffusion Cloth	Free	Max	1 sheet	Free
10 Watt LED Chips (White)	$6.28/chip	Max - Via Amazon	6 Chips	$37.68
10 Watt LED Chips (RGB)	$6.28/chip	Max - Via Amazon	6 Chips	$37.68
Foil Tape	Free	Max	1 Roll	Free
12x12x1/16 inch Aluminum Sheet	$6	Makerspace	12”x12” sheet	$6.00
Thermal Heat Paste	Free	Max	1 Tube	Free
Assorted Hardware	Free/Varies	Max and Makerspace	Free/Varies	$8.60
Matte Black Spray Paint	Free	Max	1 can	Free
Electrical (wires, resistors, relays, Buttons, etc.)	$16.15	Max and Makerspace	Varies	$16.15
Total				$127.96

Table 5.2 Table of Final Materials. A cost breakdown of all the materials used in the final production of the prototype.

Fabrication Methods

Refer to Appendix C for more complete fabrication methods.

3D Prints

The mounting joints, ring housings, adjustable arms, and arm housings were designed in SolidWorks and 3D printed with PLA with the exception of the mounting joints which were printed with tough PLA. Additionally, the arm housings needed to have their holes tapped with a M2x0.4 thread.

Ring Heatsink

From a 12x12x1/16 inch aluminum sheet, a washer shape with an inner diameter of 2.65 inches and an outer diameter of 5.15 inches was cut with a band saw. This washer was placed on the ring housing, and the LEDs were placed in their positions. Then, using a permanent marker the mounting holes of the LEDs were marked on the aluminum. Next, the holes were drilled with a 2.4 millimeter bit in a drill press. After drilling the holes, a thin layer of thermal heat paste was applied to the surface of the aluminum where the LED chips would contact it. Finally, the LED chips were secured to the heat sink with M2 bolts and threaded brass knurlings. The LED chips were secured so the order alternated through the ring (i.e. RGB, White, RGB, White, etc.)

Arm Heatsinks

Four 0.8x4 inch rectangles were cut from the aluminum sheet with the band saw, and the edges were smoothed with a belt sander. The LED chips were centered on the aluminum and a sharpie was used to mark the mounting holes on the aluminum. These holes were drilled with a 1/16th inch bit in a hand drill. One heatsink was slipped through the slits in each housing. Then, thermal heat paste was applied to the aluminum, and the LED chips were secured to the housings with M2 screws through the heatsinks and into the tapped holes of the housings (Two arm housings had RGB LEDs secured and two got white LEDs). Next, the protruding bit of the heatsinks were bent towards the female mounting part of the housing at a 90 degree angle with two needle nose pliers. Lastly, a layer of foil tape was adhered to the arm housing interiors.

Electronics

Once all of the housings were complete, the white LEDs were soldered together in three sets of two LEDs in series, and the sets were connected in parallel. The same was done for the RGB LEDs (Figure 5.1). The Arduino Uno was programmed with four separate push button codes (Appendix D) that were wired to four push buttons in the breadboard. Relays were then connected to the Arduino and corresponding push buttons (Figure 5.2). In order to protect and organize the Arduino setup, a simple, open top, scrap wood box was created to house it.

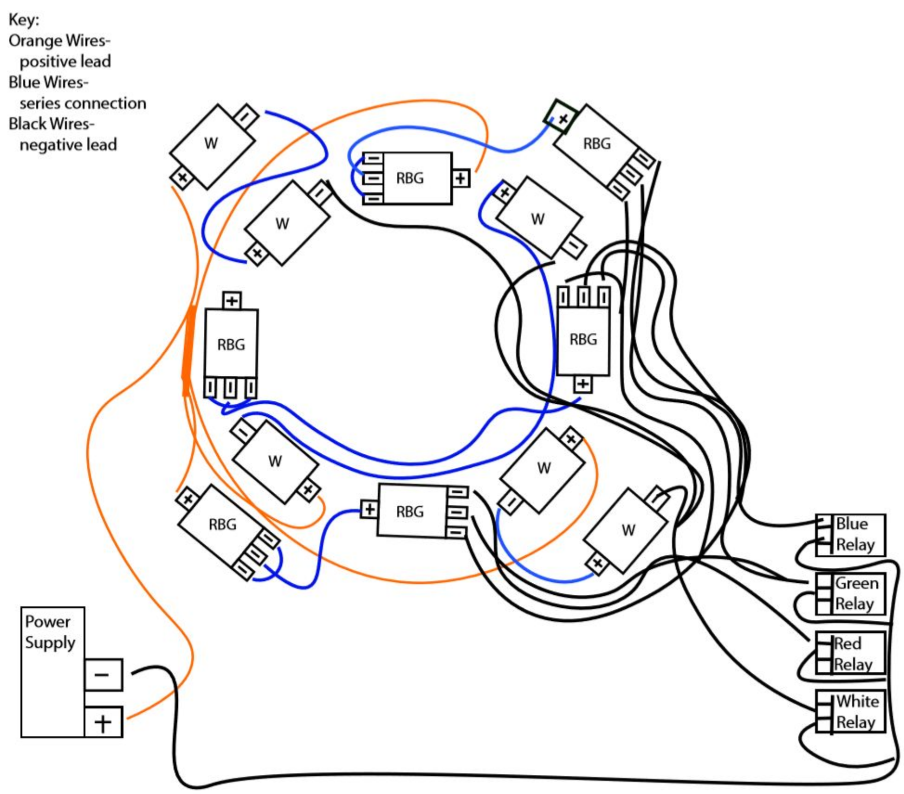

Figure 5.1 Final wiring diagram for the LEDs. A diagram of the final wiring which was done in two sets of three LEDs in series which were all then connected in parallel and connected to the power supply.

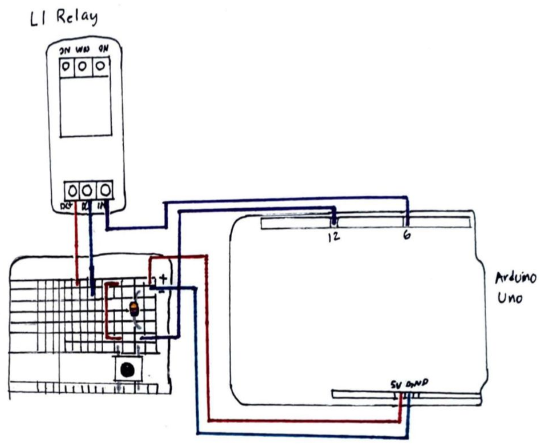

Figure 5.2 Wiring diagram for the Arduino Uno. Above is a diagram of how the relays, push buttons, and Arduino are wired together. This same circuitry was replicated four times in association with the four push buttons. See Appendix C for full wiring description.

Arm Assembly

Once all of the wiring was completed, two digits of the arms were linked to each other, a mounting point on the ring, and to an arm housing with wing nuts and 6/32 inch bolts.

Results

Once the 3D prints were printed, a handful of tests were conducted to determine the durability of the parts. Further testing was conducted once the prototype was fully assembled, to evaluate its actual effectiveness in the lab setting. Extraneous testing was placed in Appendix E.

Basic Durability Test

Each 3D printed part was dropped from a height of 50 centimeters and their abilities to withstand the impact were observed.

Ring and Arm Joint Test

The ring housing was placed flat on the edge of a table and one digit of the adjustable arm was connected to one of the rings connection points. Another digit of an arm was connected to the digit attached to the ring. This arm was pointed over the edge of the table so the arm was parallel to the floor. Then, a loop of string was passed through the male part of the outer arm and bolts that weighed about 4 ounces were placed one by one. Bolts were placed in the loop until one pound was being supported.

Lab Test

The fully assembled prototype was taken to Russell Labs to be connected to the HyperScanner. Then, a power supply was connected to the appropriate wires and each color of light was cycled on and off once to ensure they still worked. Next, the mounting joints were fastened to the actuator arm with the mounting brackets and screws. The ring housing was attached to the actuator arm via the joints. The actuator arm was moved to a location above a white balance card. The adjustable arms were pointed at the white balance card and the white LEDs were turned on. The camera made a reading about the brightness and quality of light which was displayed in the software that the client uses to take hyperspectral imaging samples. This data was used to draw conclusions about the intensity, evenness, and presence of shadows.

Test Results

All of the 3D printed parts withstood the drop from 50 centimeters and did not sustain any damage. The ring joints and arm joints were able to sustain a one pound load while staying in a locked position parallel to the floor. The first lab test yielded mostly photons in the 0% intensity range and the camera was barely registering the produced light wavelengths. The second lab test had around 25% of observed photons in the 90%-100% intensity range and the camera was clearly measuring the wavelengths of light being produced (Figure 6.1).

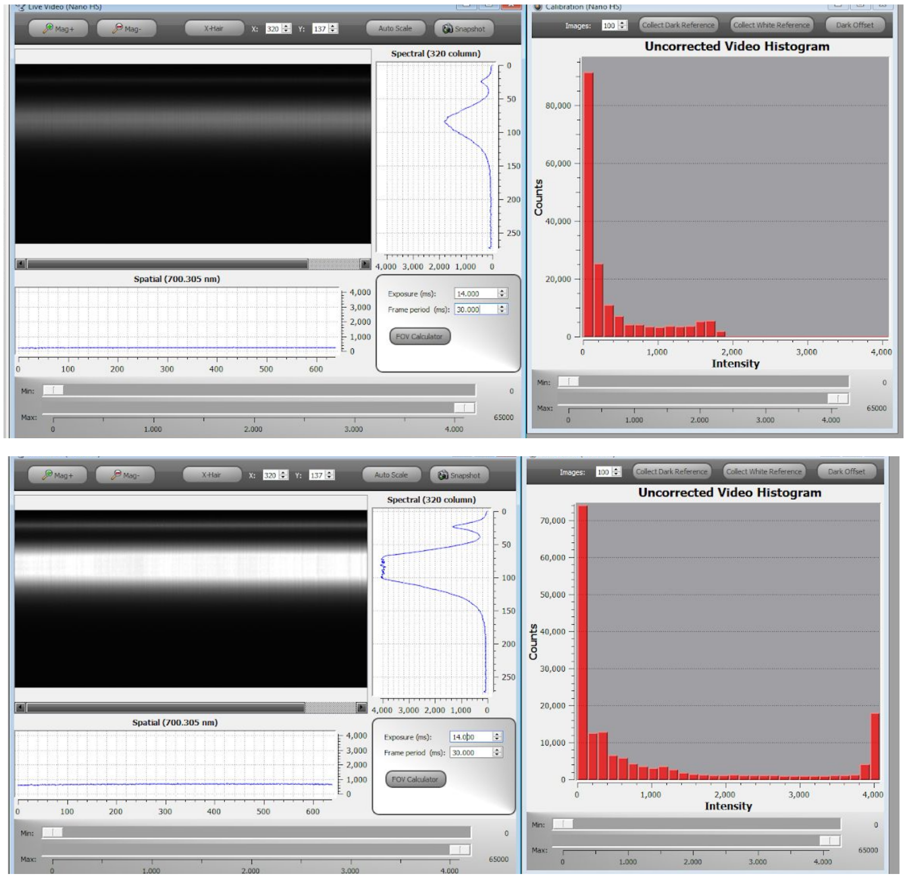

Figure 6.1 Lab Testing Results. The upper image corresponds to the initial test of the lighting system when the lighting was not even or bright enough. The lower image corresponds to the test of the updated wiring that allowed the LEDs to run at full power which satisfied the brightness and evenness requirements.

Final Prototype Evaluation

The durability test proved that the prototype could handle stress from potential slight misuse. The joint test confirmed that the design would be able to handle stress placed on the ends of the arms and still stay in its locked position for any intended use. The lab test results were the most important because they directly corresponded to the usability of the prototype with the HyperScanner. The initial wiring of the lighting system was all in parallel because that was easiest for the team to understand. However, that setup did not allow each LED to use its full power. In turn, the lighting system was not bright enough, or even enough, and it cast shadows. However, the switch to three parallel sets of two LED chips in series for both the RGB and white LED networks allowed the system to emit well above the threshold of 25% photons in the 80-90% intensity range. The switch allowed the system to emit around 25% of its photons at the 90-100%

intensity range (Figure 6.1). Another change to make the system better suited to the actuator arm was to have the joints mount to adjustable CNC rails on the actuator arm which required a reprint of the joints. This allowed the ring to be adjusted up and down on the actuator arm.

Final Design and Prototype

After a handful of 3D prints, a round of testing and many changes the prototype came to its finalized form. These changes included reducing the number of LEDs in the ring housing from twelve to eight. The RGB and white LEDs networks were resoldered from all in parallel to having three sets of two lights in series with the sets connecting in parallel. This change allowed the LEDs to receive full power. Aluminum heatsinks were also incorporated into the final design to ensure that the LEDs would not overheat and melt the housing.

In order to accomodate the heatsinks in the arm housings, two slits were added to the arm housings. Additionally, the housings were changed from a conical shape to a properly focused ellipsoidal shape. Finally, the joints were mounted farther apart on the actuator arm and had their male and female parts lengthened to increase adjustability. The final prototype consisted of the 3D printed parts in Figures 7.1-7.7.

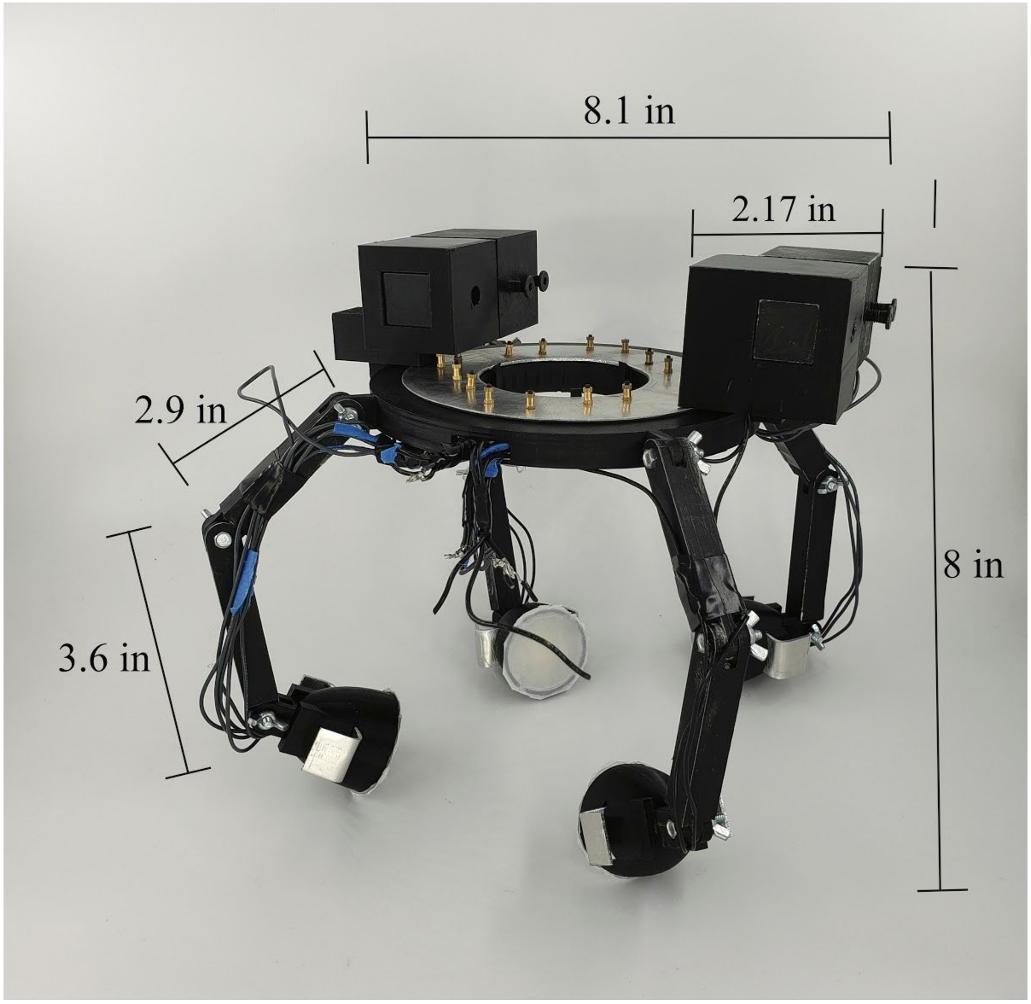

Figure 7.1 The final light ring assembly. This is the full assembly of the ring light mounted onto the actuator arm with the arms pointed towards the inside of the ring. All of the dimensions of these parts are detailed in Figures 7.2-7.7

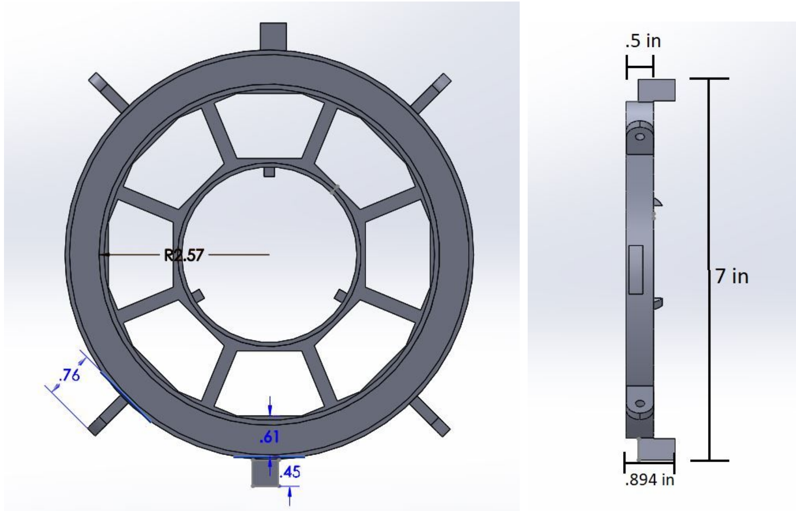

Figure 7.2 New Ring Light Designs Bottom/Side View. The new features are the addition of cubes for the mounting, larger holes for easier LED chip access, a channel in the wall for the easy routing of wires, and holes in the wall for the threading of wire.

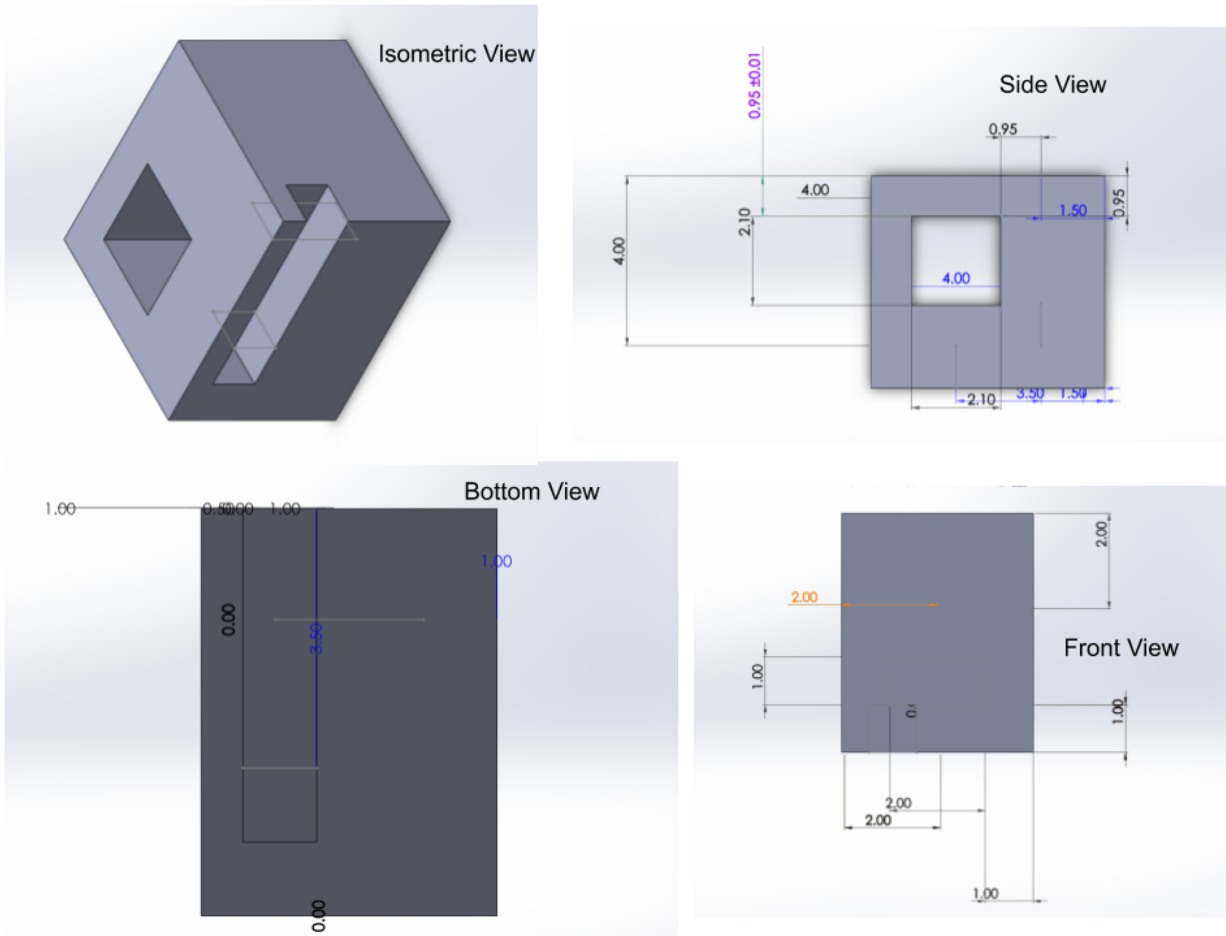

Figure 7.3 Various views of the right female mounting part. This includes the isometric, side, top, and bottom views of the female mounting part which connects by housing the male part inside of it and then is mounted onto the right side of the ring. It has been updated with larger channels.

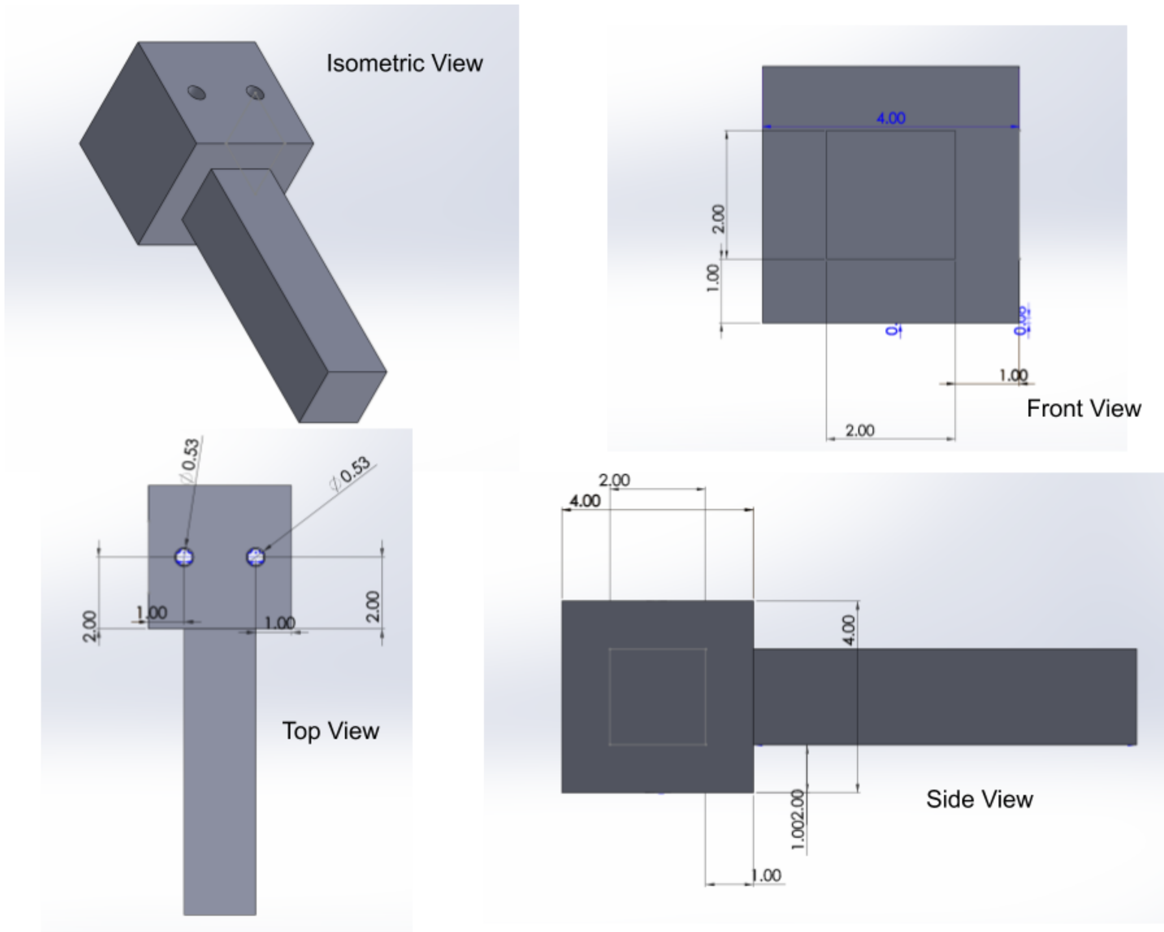

Figure 7.4 Various views of final male mounting part. This shows the isometric, side, top, and front views of the male mounting part which connects by sliding into the female part to create a joint with final modifications of an extended rail.

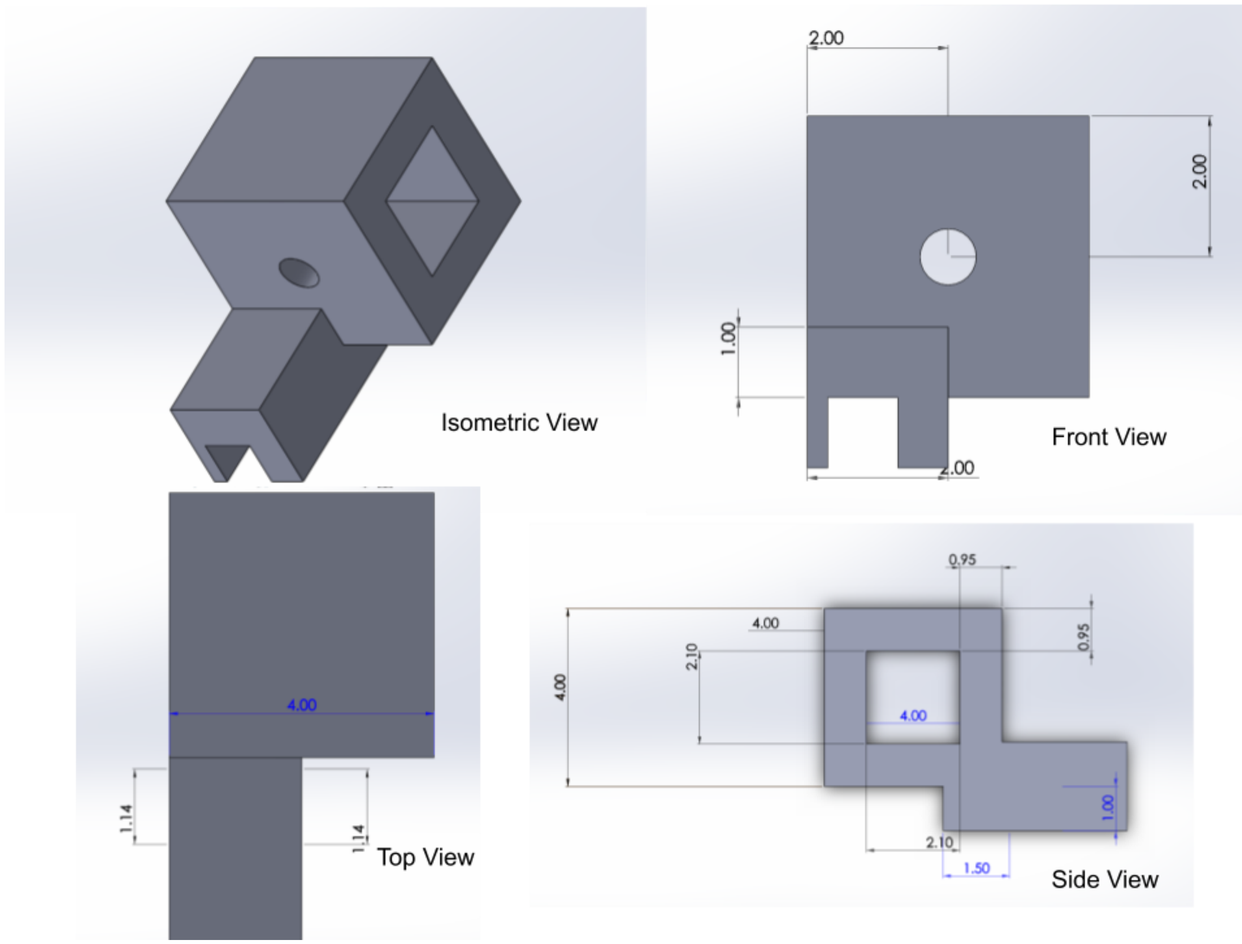

Figure 7.5 Various views of the final left female mounting part. This includes the isometric, side, top, and bottom views of the female mounting part which connects by housing the male part inside of it on the left side of the ring. It has been updated by having an extended channel.

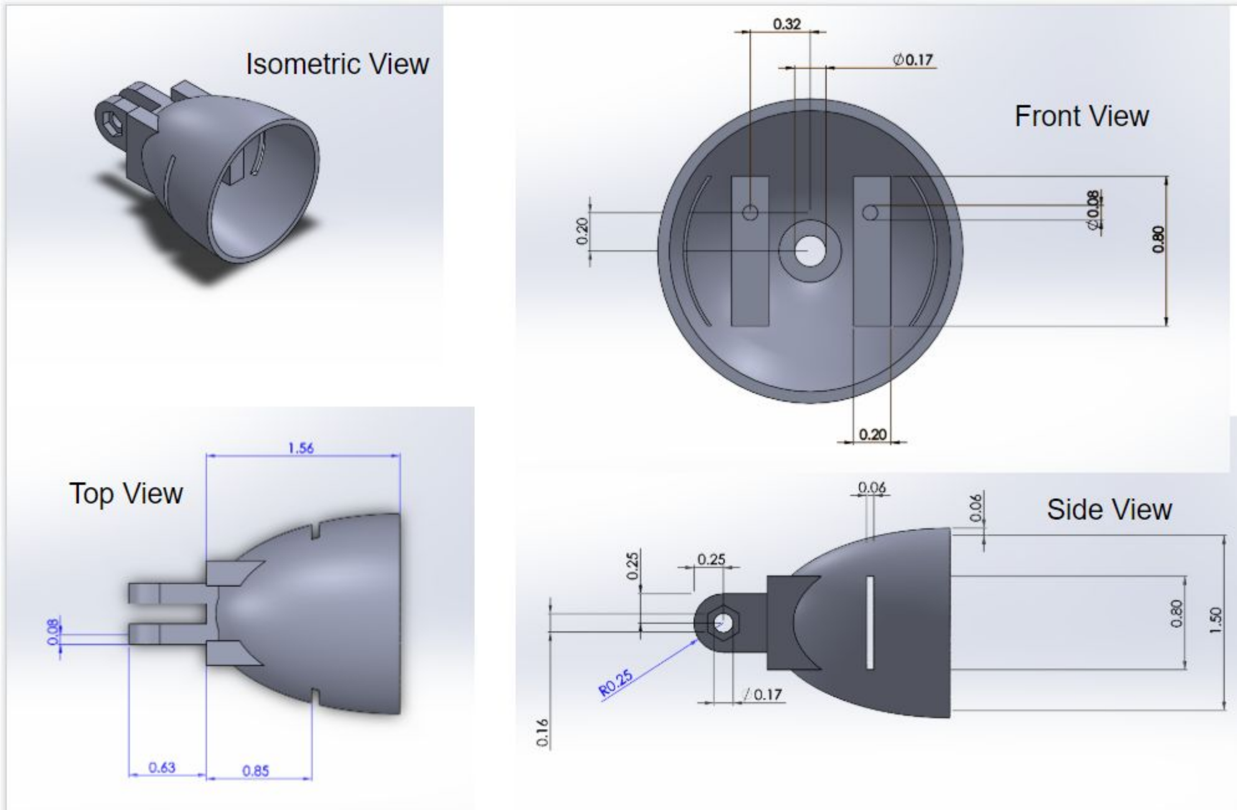

Figure 7.6 Various views of the final arm housings. This includes the isometric, side, top, and bottom views of the final arm housings for the LED chips. The design was changed into an ellipsoidal shape to properly reflect light and slits were added in the sides for the heatsinks.

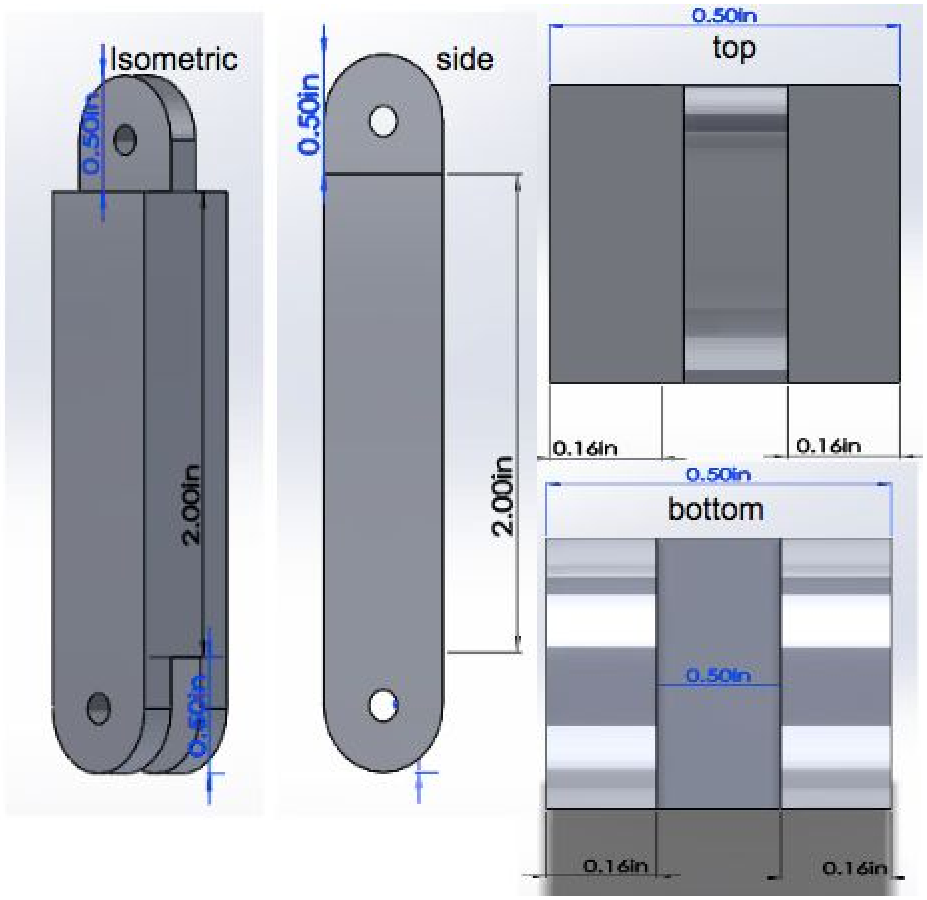

Figure 7.7 Various views of the final adjustable arm digits. This includes the isometric, side, top, and bottom views of the final adjustable arm digits for the arm housings. The design was not changed from the original design.

Conclusions

The previous lighting system had shortcomings in its brightness output, heat dispersion, light evenness, and color output capability. The final ring light design (Figure 7.1-7.6) has 12, 10W LED chips that illuminate the sample while producing less heat than the previous system. The ring light system also uses RGB LED chips to output red, green, and blue light. The arm housings' positions can be manipulated using the adjustable arms to illuminate various angles. These LEDs are wired in sets of series that are in parallel which are controlled by an Arduino with push buttons.

The design process was full of learning. The team learned how to overcome differences in ideas by working to compromise and clearly communicating their ideas to the team. The team also learned how to build on each other's designs to create a higher quality product. From this process multiple designs were created as shown in Table 3.1.

When the ring light was chosen through the design matrix, the team worked on fabrication of the design. Initially the process went smoothly, until the LED chips arrived. The initial wiring method was no longer applicable because the RGB LED chips had split anodes. The design process was used to determine how to connect the LEDs in the arrangement the client desired. The ring light housings were also found to be flawed; they were not big enough to contain the heatsinks. This issue was fixed by printing slits in the sides of the housings; these slits allowed the heatsinks to protrude from the housings and bend upwards toward the arm. Lastly, the ring light did not produce enough high energy photons to illuminate the sample. This was solved by going through the design process to find solutions. It was decided to lower the entire system by 13 cm. Additionally, the LEDs had to be wired in a different arrangement.This solution was tested and it was found that the light meet the parameters introduced by Max.

Despite having a final design, there are still design elements that could be improved. The heatsinks could be made more effective at dissipating heat and the ring and arm housings could have their shape optimized to better focus the light.

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Max Lien

Katie Kalscheur

Marissa Harkness

Makerspace Staff

Karl Williamson

Evan Wildenberg

TeamLab Staff

Dr. Barker

Appendix A: Product Design Specifications

Function:

This device is meant to be an improvement to the current lighting system that is attached to the actuator arm of a CNC machine. This CNC machine is being used for hyperspectral imaging of various plant samples. This device needs to evenly and brightly illuminate a small area to encompass a sample in bright enough light to be read by the spectropsy software.

Client requirements :

- Brighter than previous system
- Modular and ease of access
- Covers area under lense where sample would be placed
- Various colors (Red, Green, Blue, White)
- Lightweight (under 7.3kg)
- Same or improved evenness of light over sample area
- Does not burn samples
- Does not melt lighting housing
- Minimization of shadows for spectroposy readings

Design requirements:

1. Physical and Operational Characteristics
    - Performance requirements:
        - The device will have to illuminate a small with even and consistent lighting with either, red, blue, green or white light for a maximum of 20 minutes. The lighting power is drawn from a 300 watt DC power supply with a peak voltage of 30V.
2. Safety:
    - Use lights that do not overheat with extended use. Housing around lights should be able to withstand high temperatures. Electrical wires should not be exposed and should not get in the way of the CNC machine. Wires also need to be contained so they do not get wrapped around any of the moving parts.
    - Lights should be shielded or protected from average user so that they do not suffer from temporary blindness.
    - Lights should be housed out of reach of user to avoid contact and burns to the skin of the user.

3. Accuracy and Reliability:
    - Has to provide even light for each sample and the light brightness and evenness should be the same for all tests and samples done. It needs to be able to illuminate red, blue, green, and white light.
4. Life in Service:
    - The design needs to last as long as possible. The only part that should be failing is the LEDs themselves.
    - LEDs need to last in 20 minute application periods and last for warranty period.
    - All 3D printed parts should last the lifetime of the LEDs.
5. Operating Environment:
    - Controlled laboratory environment.
    - There may be some elevated level of humidity in the room.
    - Human interaction with device like adjusting the device.
6. Size:
    - 12x12x12 inches is the maximum area dedicated to the device.
7. Weight:
    - It needs to be less than 7.3kg, which is the weight limit of the actuator arm.
8. Materials:
    - 3D Printable material
    - Halogen lamps cannot be used.
    - LEDs should be used in place of halogen bulbs.
    - ABS plastic for the lighting housing is **not** recommended since it melts easily.
        - Black PLA is the preferred material for 3D printing.
    - Aluminum should be used for heatsinks because it is the most lightweight and effective at conducting heat away from the LEDs
9. Aesthetics, Appearance, and Finish:
    - Spray paint the housing matte black.
    - Smooth edges (not sharp enough to cause injury).

Production Characteristics

1. Quantity: number of units needed
    a. One unit is needed for application.
        i. Must be reproducible with appropriate documentation.
2. Target Product Cost:
    a. Cost effective while still maintaining structural and physical integrity.
        i. Budget of about $200.
    b. It should be consumer grade.

Miscellaneous

1. Customer:
    a. Matte black finish is preferred to reduce glare off of parts.
    b. Red, green, blue, and white light is needed.
2. Patient-related concerns:
    a. None due to the open source aspect of this project.
3. Competition:
    a. HID lighting.
    b. Current spectroscopy lighting.
    c. Ring lights made by various companies.

Appendix B: Materials List

PLA:

Polylactic Acid Plastic (PLA) was used to print the 3D parts for the various structures. PLA was chosen over the other option of tough PLA because they both have the same melting points, and after consulting the Makerspace guidebook on printing filaments, the two materials appeared to have the same torque strength with tough PLA only having a slight edge. PLA is also cheaper to use. With the advantages of being more cost effective and meeting the needs for heat resistance, PLA was chosen to be the material of choice for the 3D prints.

Arduino:

An arduino was used to control the lighting and handle user input. This was chosen over a raspberry pi due to the ease of use, its availability, and extra components (provided by Max).

Breadboard:

A breadboard was used to handle the connection of wires and the electrical circuits that were created for the lighting of the project (provided by Max).

Diffusion Cloth:

Diffusion cloth was used to disperse light coming out of the individual LED housings to provide even lighting on the subject.

10 Watt LED chips (RGB and White):

10-watt LED chips were chosen over strip and 50-watt LED chips because they had the most appropriate power consumption and brightness. The strip lighting was too dim and the 50-watt LEDs were too bright. The 10-watt LEDs also had a more ideal size profile to fit in the final design housings. Additionally, the 10-watt LED chips were easier to cool with smaller heatsinks.

Foil Tape:

Foil tape was used on the inside of the LED arm housings to reflect light from onto the subject. Because LEDs do not create a focused beam of light, the foil tape helped them focus on the subject.

Aluminum Sheet:

The aluminum sheet was used to create an aluminum ring heatsink. The aluminum was used because of its high thermal conductivity. It helped disperse the heat that the LEDs produced. Small rectangles of aluminum were also used as heatsinks for the individual LED housings.

Thermal Heat Paste:

This paste was used as a connector between the LEDs and their respective aluminum heatsink. It is used as an extra conductor to disperse more heat away from the housing to ensure that the LEDs do not melt the PLA.

M5x 0.8 Screws:

This screw thread was chosen for the mounting brackets because the threadings are the same as the attachment points on the actuator arm for the lighting system.

6/32” Screws:

This screw thread was used for the arms and connection joints to the ring light as it was the correct diameter of the holes in the joints.

M2x 0.4 Screws:

This screw was chosen for the LED housings as it was the smallest screw available and had a corresponding Brass knurling.

Hex Nuts:

These nuts were used to screw and clamp the arm points to the ring light and to each other. Nuts with wings were chosen to make the arms easily adjustable by hand.

Matte Black Spray Paint:

This specific color was chosen due to the client requesting the system be black in the finished product.

Threaded Brass Knurlings:

Threaded brass knurlings were used as an alternative to hex nuts in attaching the LEDs to the ring heatsink because they could easily be adjusted with fingers but still allowed a tight hold on the bolts.

Appendix C: Fabrication

Ring Light Housing

This ring housing was created using the 3D printers provided at the Makerspace. The filimanet used for this printing process was PLA because it is cost effective and has a high melting point. The file that was used for the the 3D print for the design was made in SolidWorks. Once the file was finished in SolidWorks, it was sliced in Cura and 3D printed. Once the print was finished, the ring was removed from its plastic supports and filed down to accommodate for the swelling of PLA during the print process. The ring housing is shown below in Figure 13.1

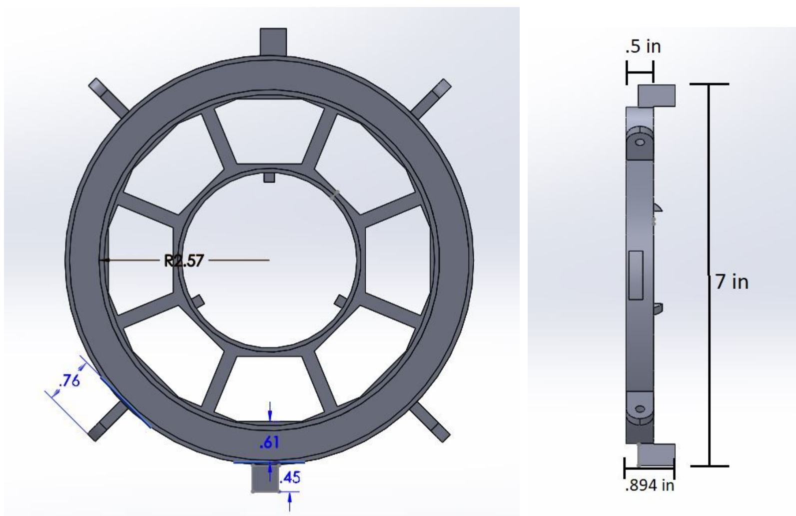

Figure 13.1 New Ring Light Designs Bottom/Side View. Bottom and side views of the finalized 3D print of the ring housing.

Aluminum Heatsinks

A permanent marker was used to trace two circles on a 12x12x1/16th inch aluminum sheet purchased from the Makerspace. The inner circle had a diameter of 2.65 inches, and the outer circle had a diameter of 5.15 inches. The aluminum was cut on the band saws in the Team Lab, and the edges were finished with the belt sander. Then, the heat sink was placed into the ring, and the LEDs were put in position. A permanent marker was used to mark the mounting holes of the LEDs on the aluminum which were put out with a drill press.

The same sheet of 1/16th inch aluminum was used for arm housing heatsinks that was used for the ring light heatsink. On the aluminum sheet, 4 rectangles 3.65in by 0.8in was traced out using a sharpie. The LED chips were then set on the aluminum and marked where they would need holes drilled to attach them. Then the 4 heatsink templates were brought to the Team Lab and the holes were drilled out with a 2mm drill. After drilling the holes, the heatsinks were cut out of the aluminum using a bandsaw. The edges were grinded so they were not sharp. Once the heatsinks were done, they were slipped into the slots in the arm housing and bent to 90 degrees on both sides using two pairs of pliers.

Mounting Joints

The joints used to mount the ring to the actuator arm were made using SolidWorks designs of the actuator arm and camera mount that were obtained from the client. The finished design files were 3D printed and sliced using Cura. These joints were made of tough PLA. The finished prints were separated from their supports and filed down to ensure they would join properly. The joint parts were placed inside one another with the male end fitting inside the female cavity. The female joint channels were placed onto nubs located on the ring light and adjusted to position the ring under the camera. The male joints were placed on the side of the actuator arm and tightened down using bolts. The male joint is shown below in Figure 13.2, and the female joint is shown in Figure 13.3 and 13.4.

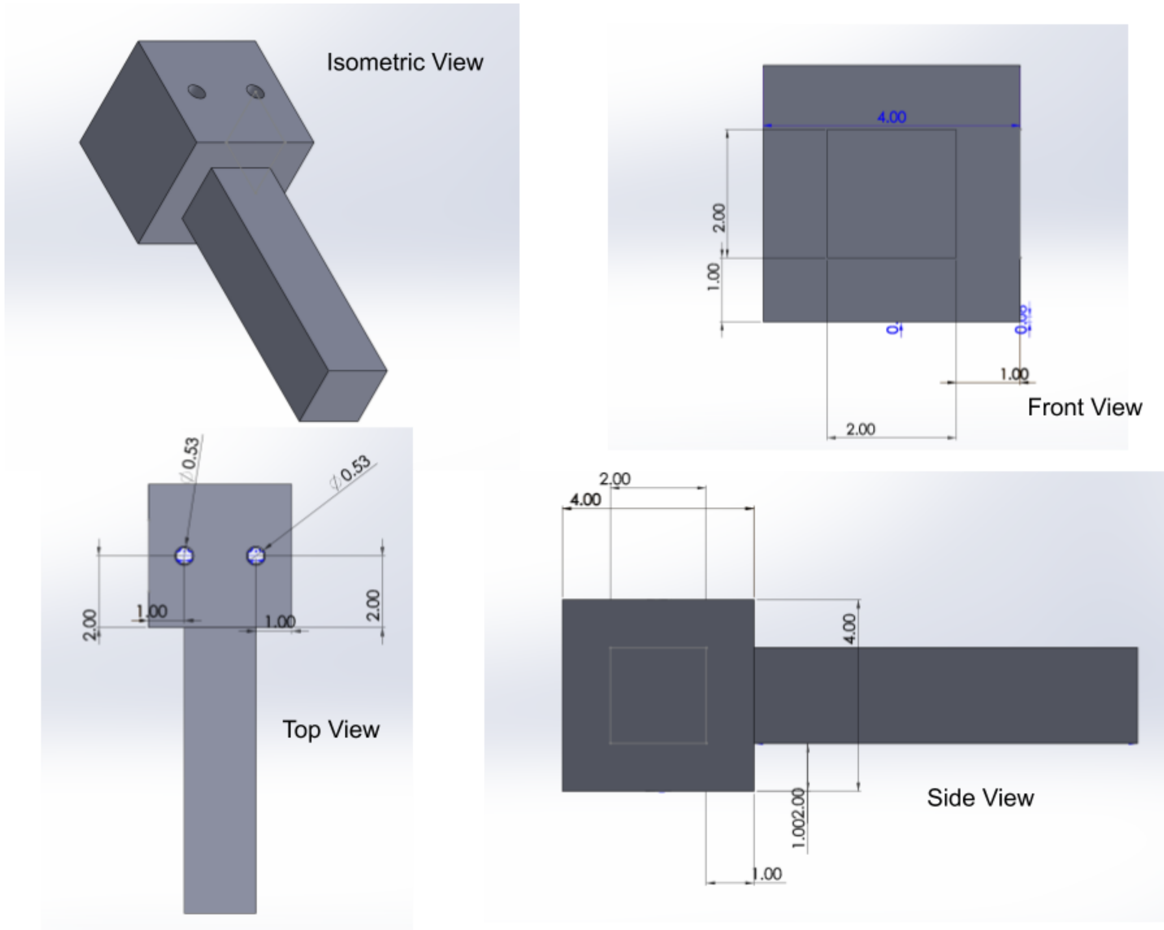

Figure 13.2 Various views of male mounting part. This shows the isometric, side, top, and front views of the male mounting part which connects by sliding into the female part to create a joint.

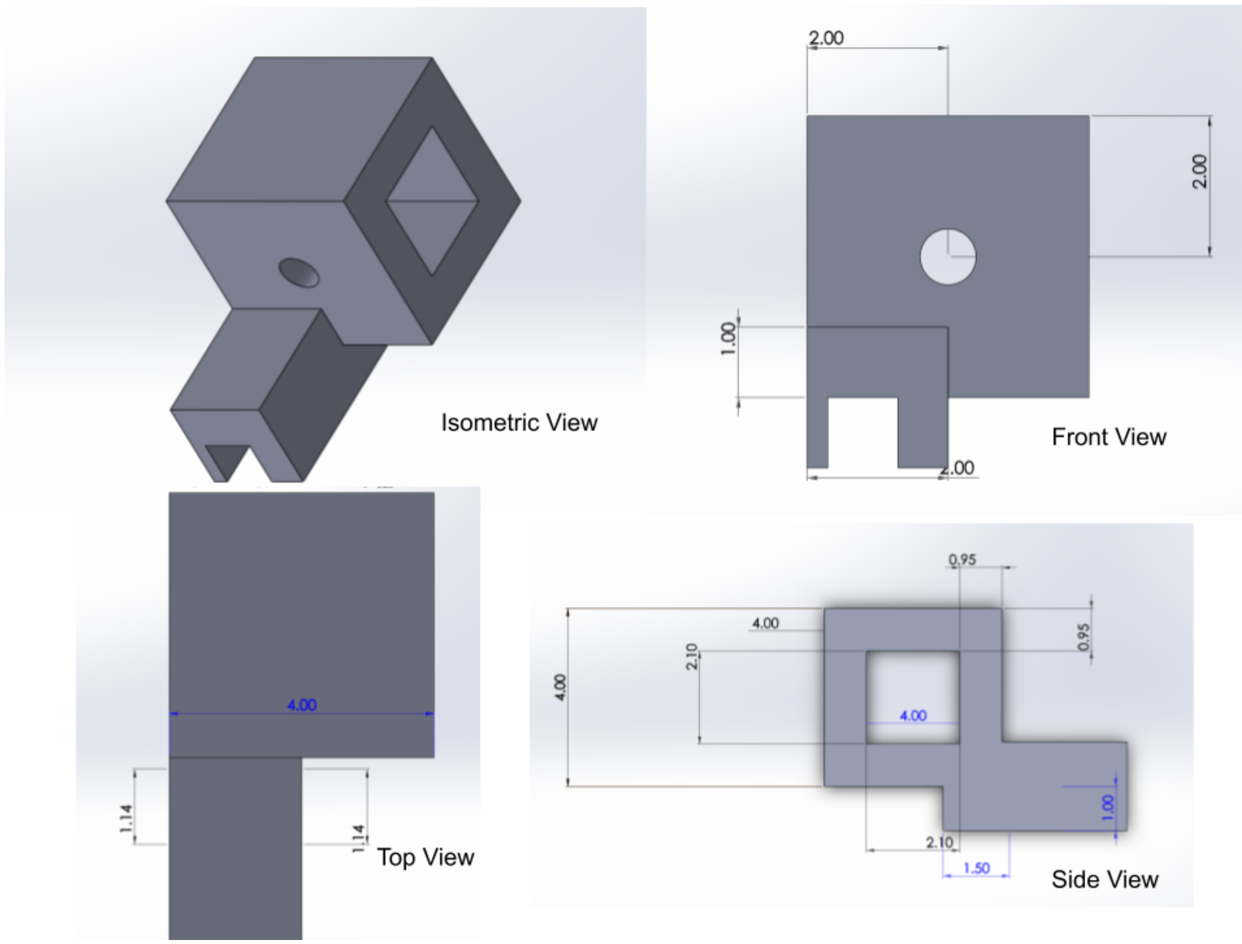

Figure 13.3 Various views of right female mounting parts. This includes the isometric, side, top, and bottom views of the female mounting part which connects by housing the male part inside of it which then is mounted to the actuator arm. The right part has an extended channel on the bottom for better adjustability and to center the ring under the camera.

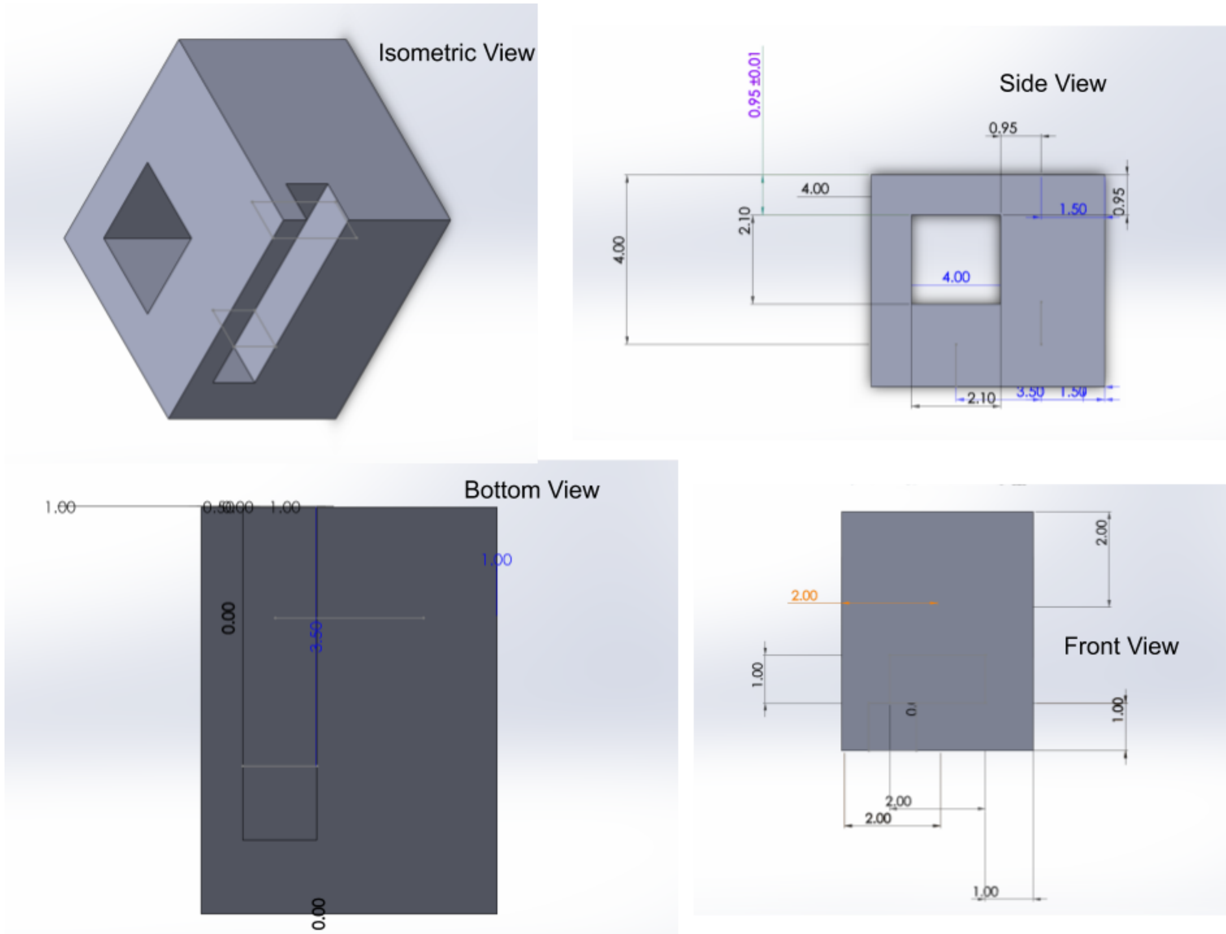

Figure 13.4 Various views of left female mounting parts. This includes the isometric, side, top, and bottom views of the female mounting part which connects by housing the male part inside of it which then is mounted to the actuator arm. The left joint has a larger inside channel to compensate for the offset camera; this is done to center the camera in the ring light.

Adjustable Arm Digits

The arm digits were made using a SolidWorks design containing a 2in base with .5in female and male counterparts. The finished design files were 3D printed and sliced with Cura. Each of the arms are printed with PLA. The finished parts were stripped of their supports and filed down so that the female and male joints fit. The female and male joints interlock with a wing nut and hex cap screw which lock into place on the arm digits. This allows for the arms to lock into place and also be adjustable to different formations and length from the ring housing. There are eight total arms with two at each mounting point on the ring housing. The adjustable arm digits are shown in figure 7.7.

LED Arm Housings

The LED housings were created in SolidWorks and refined many times before being printed. The print was sliced in Cura and then printed in the Makerspace out of PLA. The housings were then cleaned of their support material, and the holes were tapped with an M2x0.4 tap. The housings had their aluminum heatsinks slipped through the slits in the sides. Then, these heatsinks were attached to LED chips and the housings with thermal paste and screws through the tapped holes. The interiors of these housings were covered with foil tape. Once the foil tape was placed, diffusions cloth was stretched over the opening of the housings and glued in place. These housings were then attached to the arms with 6/32 inch screws and wing nuts (Figure 13.5).

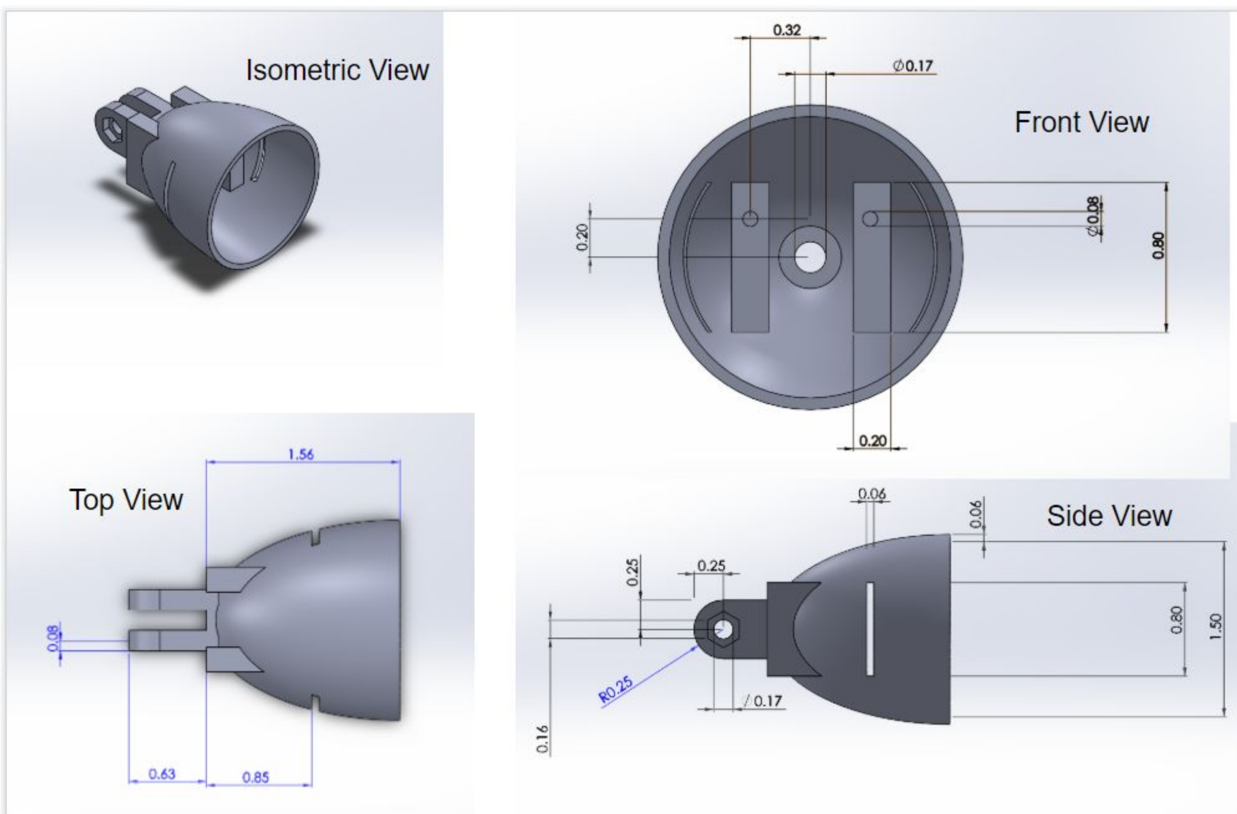

Figure 13.5 Various views of the final arm housings. This includes the isometric, side, top, and bottom views of the final arm housings for the LED chips. The design was changed into an ellipsoidal shape to properly reflect light and slits were added in the sides for the heatsinks.

Wiring for Arduino and LEDs

The Arduino Uno was programmed using a standard push button code found on the Arduino webpage and modified to control multiple separate LED units (Appendix D). The Arduino was then wired to the breadboard with the ground going to the negative rail and the 5V going into the positive rail. There were then two corresponding pins per LED pushbutton (four in total). One pin was connected to the 'DC+' stationary contact while the other was was connected to the breadboard on the same rail as one of the push button pegs. Next to this wire, a resistor was added to complete the connection. The second push button peg was grounded by placing a grounded wire next to it in the same rail. The wiring for the relay was finished by connecting a wire from the positive rail into the 'IN' stationary contact and a wire from the grounded rail into the 'DC' stationary contact. This system was then repeated three more times to account for the four separate LED systems (Figure 13.6).

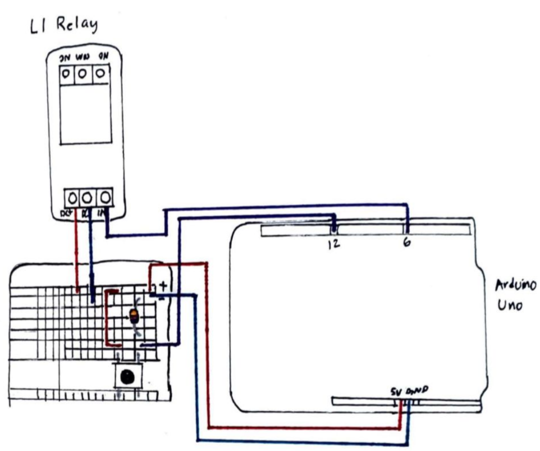

Figure 13.6 Wiring diagram for the Arduino Uno. Above is a diagram of how the relays, push buttons, and Arduino are wired together. This same circuitry was replicated four times in association with the four push buttons. See Appendix C for full wiring description.

The LEDs were adhered to the aluminum ring heatsink with thermal paste and two M2x0.4 screws and threaded brass knurlings. They were arranged on the ring alternating white LEDs and RGB LEDs with eight LEDs in total. The LEDs in the light housing were adhered to their heat sinks in the same fashion. Two lights were then soldered together in series with a total of three sets of two white LEDs and three sets of two RGBs (Figure 13.7).

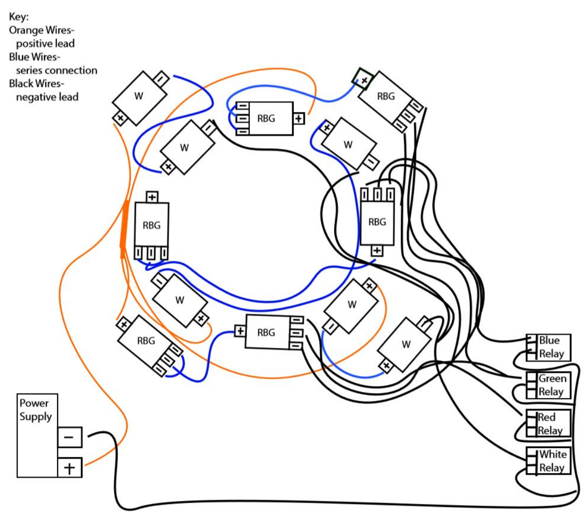

Figure 13.7 Wiring diagram for the LEDs. This is a diagram of the final wiring which was done in two sets of three LEDs in series which were all then connected in parallel and connected to the power supply.

Each color of LED lights got a separate relay to control whether it was on or off. The four relays were all connected to the ground wire of the DC power supply. The negative leads of each set of LED chips wired in series were connected to each respective color's relay to control their power state, off or on.

Final Assembly

The final assembly consisted of the the light housings, ring light, aluminum heatsink, arms, and the mount joints. The aluminum heatsink was placed onto the top of the housing while putting the wires from the LEDs through the pre-printed holes inside the ring light housing. Then, the arms were connected to the ring with 6/32 inch bolts and wing nuts. Another set of digits was added onto the previously connected ones, and then, the arm housings were connected to the arms in the same fashion. Once all of the printed parts were in place, the wires were soldered to the general connections on the ring light and the arm housings to fully connect the system. In order to install the system, the ring just had to have the mounting joints connected to the actuator arm, and each of the remaining open wire connections connected to power.

Appendix D: Code for the Arduino

sketch_mar28a

```
/* sketch 3
turn on a LED when the button is pressed and let it on
until the button is pressed again
*/
int pinButton = 13;
int LED = 7;
int stateLED = LOW;
int stateButton;
int previous = LOW;
long time = 0;
long debounce = 200;

int pinButton2 = 12;
int LED2 = 6;
int stateLED2 = LOW;
int stateButton2;
int previous2 = LOW;
long time2 = 0;

int pinButton3 = 11;
int LED3 = 5;
int stateLED3 = LOW;
int stateButton3;
int previous3 = LOW;
long time3 = 0;

int pinButton4 = 10;
int LED4 = 4;
int stateLED4 = LOW;
int stateButton4;
int previous4 = LOW;
long time4 = 0;
```

```
    }
    time2 = millis();
  }
  digitalWrite(LED2, stateLED2);
  previous2 = stateButton2;


stateButton3 = digitalRead(pinButton3);

  Serial.println(stateButton3);
  if(stateButton3 == HIGH && previous3 == LOW && millis() - time3 > debounce) {
   if(stateLED3 == HIGH){
      stateLED3 = LOW;
    } else {
       stateLED3 = HIGH;
    }
    time3 = millis();
  }
  digitalWrite(LED3, stateLED3);
  previous3 = stateButton3;


stateButton4 = digitalRead(pinButton4);

  Serial.println(stateButton4);
  if(stateButton4 == HIGH && previous4 == LOW && millis() - time4 > debounce) {
    if(stateLED4 == HIGH){
      stateLED4 = LOW;
    } else {
       stateLED4 = HIGH;
    }
    time4 = millis();
  }
  digitalWrite(LED4, stateLED4);
  previous4 = stateButton4;
```

Figure 14.1 Arduino push button code. This was the code that was activated by the push button to change the state of each relay.

Appendix E: Other Testing

LED Brightness Test

An RGB LED chip was placed at the bottom of a small cardboard box that was approximately a two inch square and 12 inches long. The surrounding environment was dark to ensure the light meter was not picking up any additional light. A power supply was adjusted to supply 9 volts and the leads were connected to the LED. The negative lead was connected to just the red anode. Then, the power supply was turned on and the LED shone up through opening of the box box. Then, a phone camera was placed on the top opening of the box where the light was shining. Using the Light Meter app by Elena Polyanskaya for iOS, the maximum lux output of the red LEDs was recorded. The light meter re-recorded the lux output four more times to get five total lux readings for the single red LED chip. This process was repeated for the blue, green, and white LEDs.

LED Brightness Test Results

The white LEDs produced the highest mean output of light at 2201.8 lux (∓111.505 lux with n=5). Red, blue, and green were all in a similar range of light outputs of 322.2 lux (∓1.326 lux), 354.6 lux (∓0.8 lux), and 609.6 lux (∓15.16 lux) (Figure 15.1).

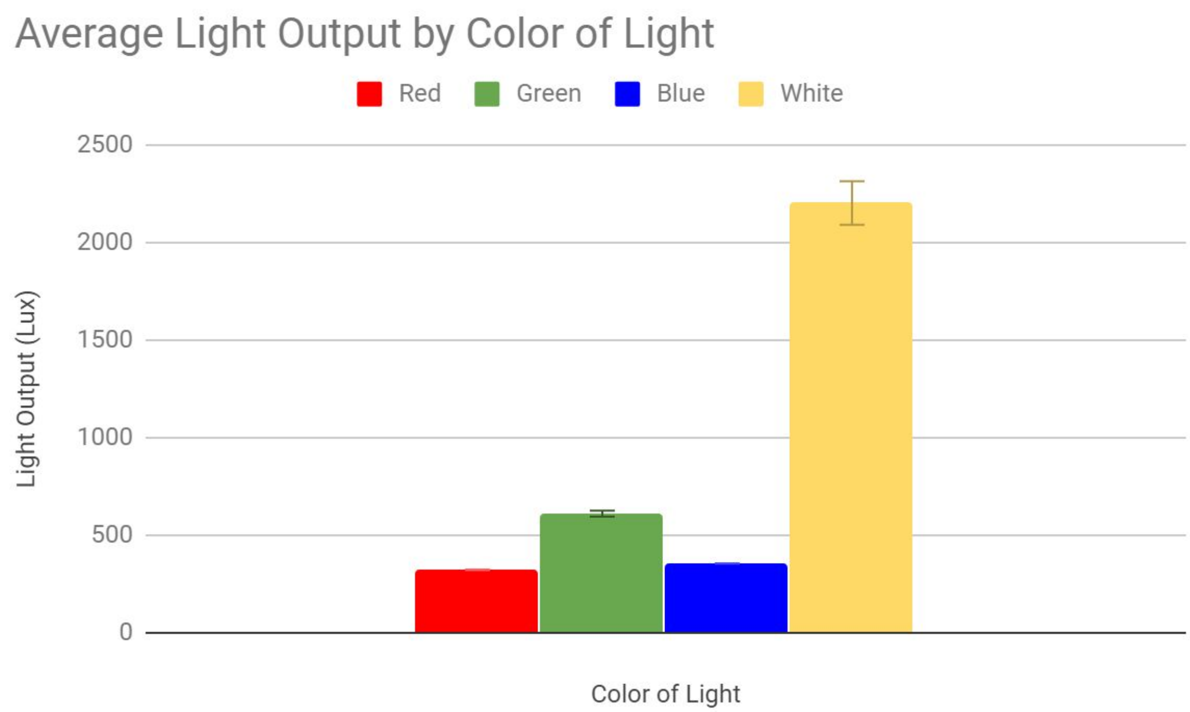

Figure 15.1 Average Light Output of a Single LED. Results of the LED Brightness Testing. All of the colors had a sample size of five readings of the maximum light output.