ECE 445

Fall 2025

Design Document

Sun Tracking Umbrella

Team 13

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Table of Contents

1. Introduction

1.1 Problem and Solution

When sitting outside in urban third spaces, it is often too hot or bright to stay there for long periods of time. Even at low temperatures, exposure in direct sun gets uncomfortable and unhealthy quickly. Many outdoor spaces do have stationary umbrellas however they only help for a short period of time which can lead to discomfort from excessive heat and brightness. This can be avoided by adjusting the umbrella throughout the day but they are often quite heavy and hard to maneuver.

Some straight umbrellas weigh between 12 and 75 pounds but the base can weigh up to 180 pounds. This means even with a joint that allows the umbrella position to be adjusted, moving it can still be very difficult. Cantilevered umbrellas tend to weigh more and can be even harder to adjust. Even advertisements [1] for easily moveable umbrellas highlight the need for at least one more axis of adjustment in order to improve sun blockage.

Our proposed solution is to create a scaled model of a straight umbrella with two joints that allow for an increased range of shade coverage. We plan to put photodiodes and solar cells on the umbrella canopy in order to implement a sun tracking system. That system will detect differences in the intensity incident on segments of the canopy. That data will then be used to drive DC gear motors that adjust the umbrella in order to redistribute the illumination across the canopy. The goal is to maximize the available shade under the umbrella while minimizing the manual effort required to adjust the umbrella. If time allows, additional features will be added to implement manual and automatic settings. Data wirelessly communicated to a browser will allow a user to switch to manual mode and adjust the umbrella as desired and then move back to automatic as wanted.

1.2 Visual Aid

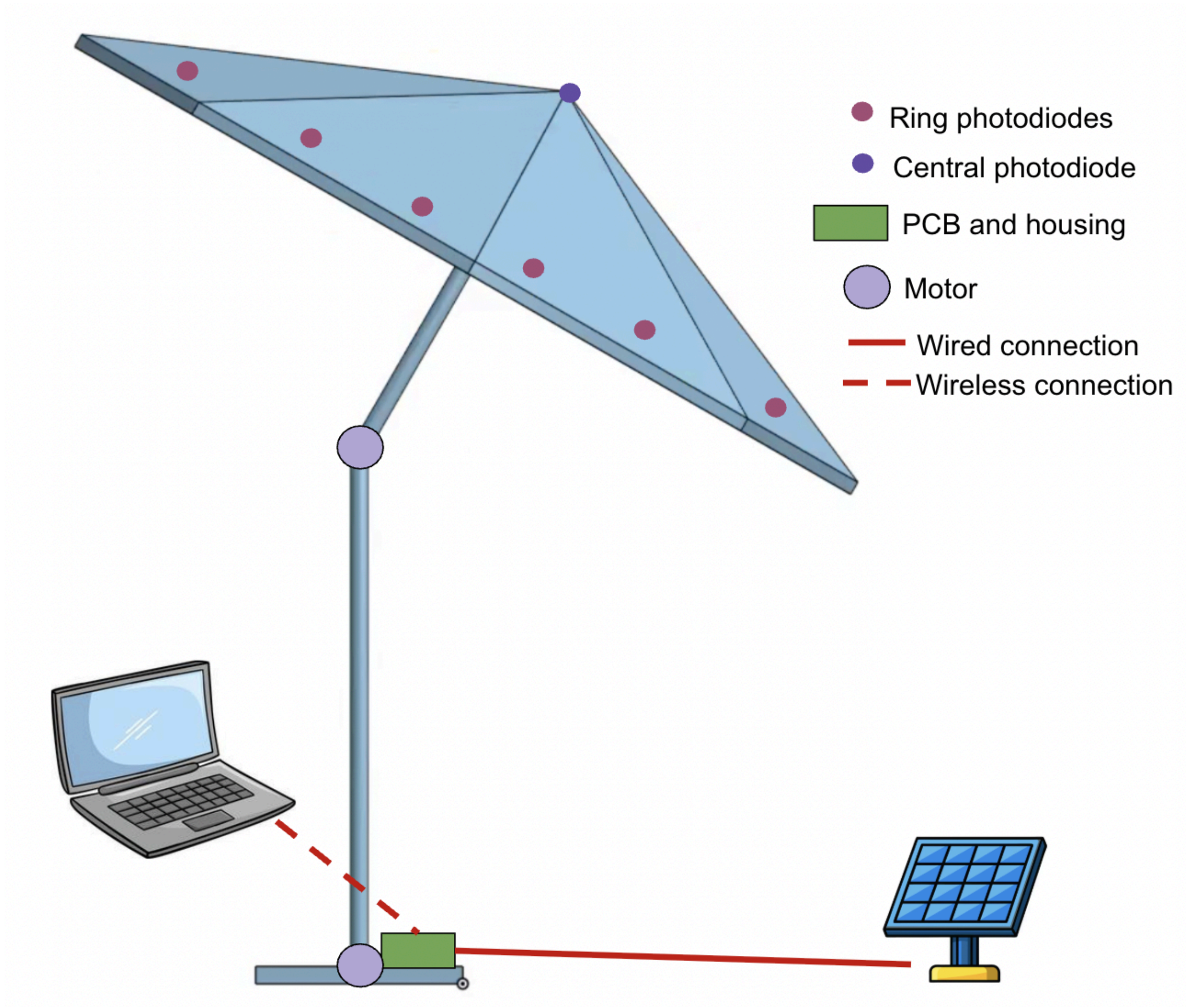

Figure 1. *Visual representation of the sun-tracking umbrella system*

1.3 High Level Requirements

In order to deem the design and implementation of this umbrella successful, all of the following high level requirements must be met:

1. The base motor and the tilting motor are able to rotate 180° around the z axis and 45° off of the z axis respectively. The motors must also be able to hold their position for at least 1 hour.

2. The photodiode array must detect differences in illumination such that a conservative voltage difference of 0.02V is seen for a difference of 30 lumens in intensity (approximately the average intensity of a phone flashlight).
3. Data from the system is wirelessly transmitted to an external screen in no more than 30 ms where it can be viewed and manual input can be sent back. A conservative aim is to poll the microcontroller every 250ms (i.e. 4 times every second).

2. Design

2.1 Block Diagram

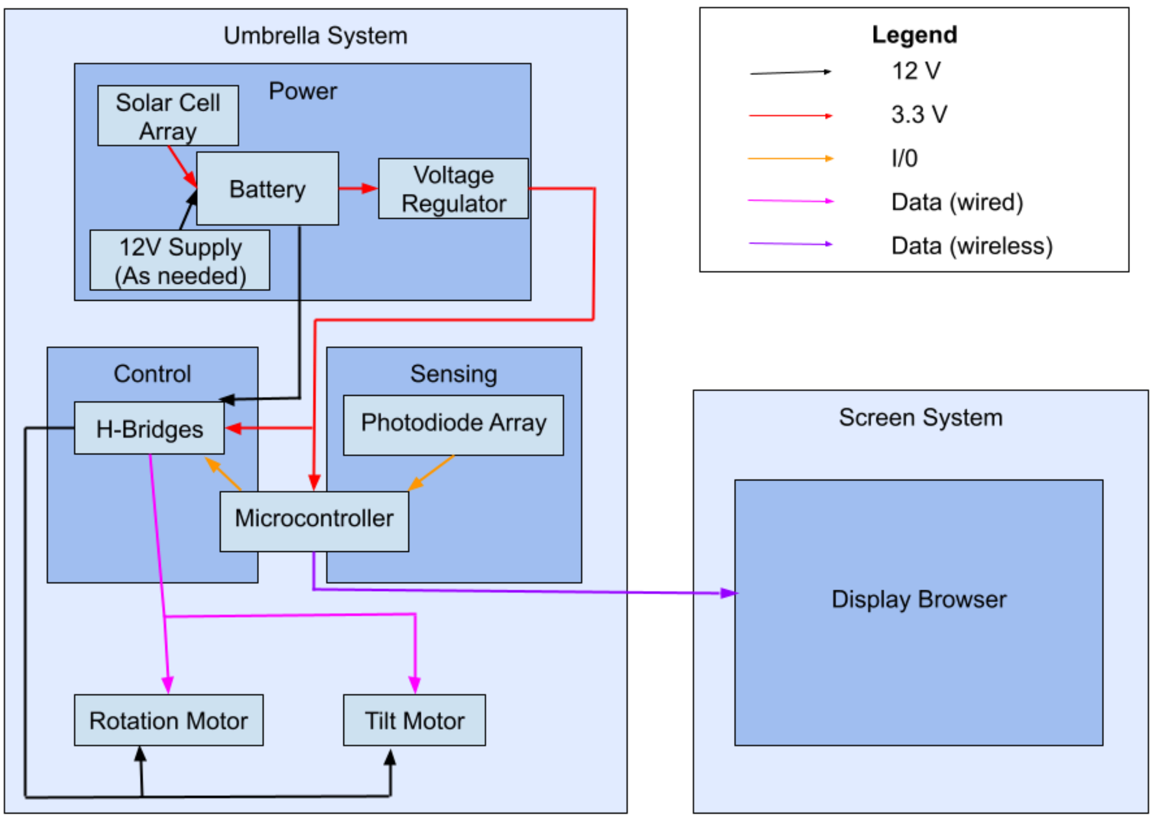

Figure 2. *Umbrella Block diagram*

The umbrella contains four main subsystems, with a fifth implemented separately. The power subsystem provides 12V to the entire system, coming from a battery which, if time allows, will eventually be charged by solar cells placed on the umbrella canopy. The sensing subsystem collects data from the photodiode array on the canopy of the umbrella, and sends those signals to the microcontroller in order to be processed. Once these signals are processed, the microcontroller will send PWM signals to the H-bridges in the control subsystem. This will then control the rotation and tilt motors so that the shade under the umbrella is maximized. Separately, the microcontroller will send data to a screen, where the data collected from the photodiode array can be visualized, and the user will have the option to manually override the umbrella settings.

2.2 Physical Design

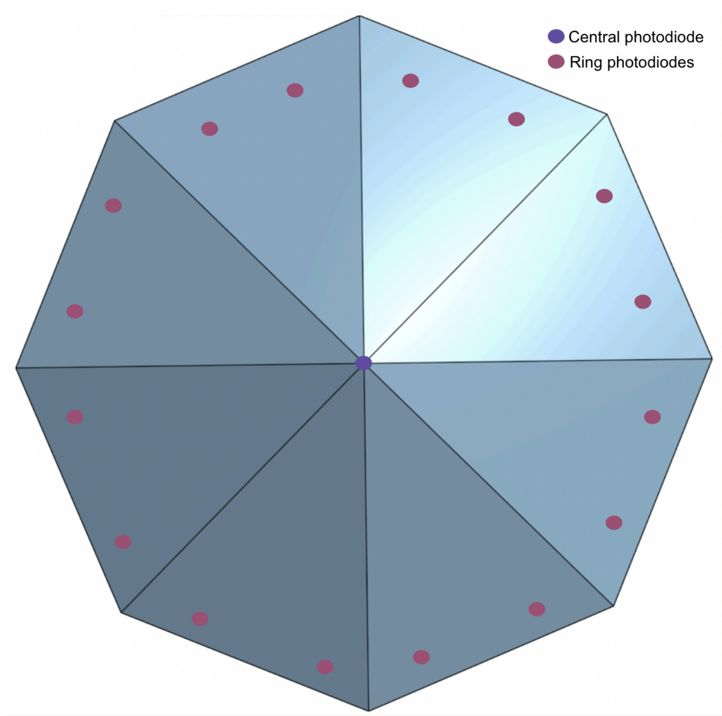

Figure 3. *Top down view of the umbrella canopy*

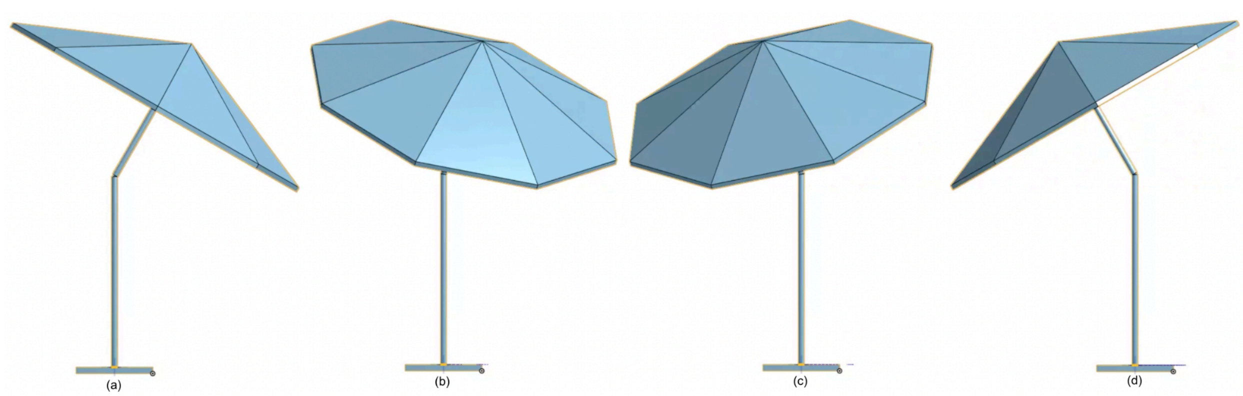

Figure 4. *Umbrella turning clockwise 180º (looking from top down) around the base*

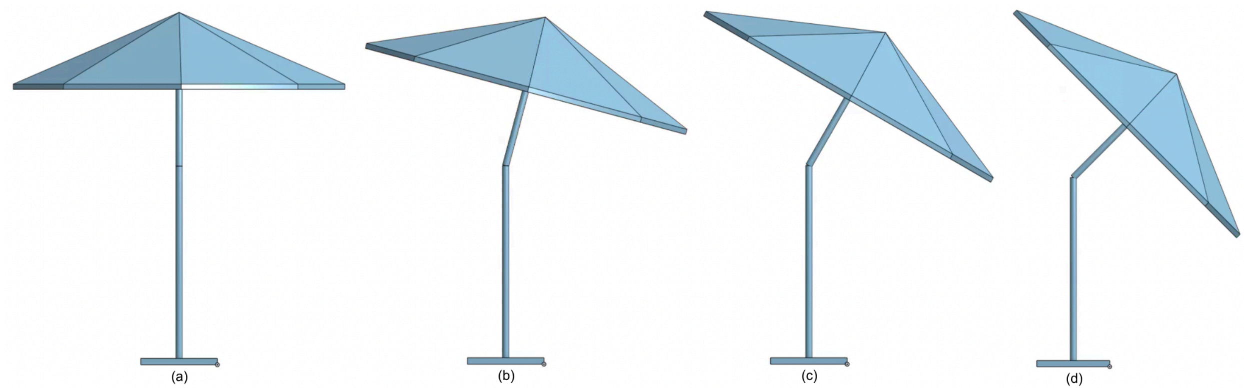

Figure 5. *Umbrella tilting down 45°*

Figure 3 shows the sensor placement with the central and ring photodiodes. The central photodiode will be the value we are trying to maximize. The ring photodiodes will be how we figure out which direction to turn and tilt the umbrella in order to maximize the value of the central photodiode. Figure 4 demonstrates the turning mechanism which will be housed in the base of the umbrella and controlled by a DC gear motor. Figure 5 shows the tilting mechanism which will be housed at the elbow joint of the pole and be controlled by a separate DC gear motor.

2.3 Subsystems and Requirements

2.3.1 Power Subsystem

The main purpose of the power subsystem is to supply all components with necessary power. Particularly, this includes providing (1) 12V to the h-bridges within the control subsystem, which then provide this power to the motors and (2) 3.3V to the microcontroller, the 16:1 multiplexer used for the photodiode input, the USB to UART bridge, and the reference voltage to the h-bridges in the control subsystem. The power subsystem will consist of a battery (GoldenMate 12V 7Ah) that provides power to the main barrel jack of the printed circuit board, which then supplies power to the various components. Within the printed circuit board, there are additional measures taken to ensure proper regulation of the voltage levels being provided by the battery. This includes decoupling capacitors, fuses to prevent overcurrent damage, and a circuit of an inductor and capacitor to ensure smooth power flow of the voltage (capacitor) and the current (inductor).

In addition to the battery power supply, ideally there will be a solar cell array in use to charge the battery as the motors and circuitry deplete the charged power. This will allow the system to be fully independent of other power sources. The solar cell array would consist of 10 solar cells, each providing up to 5V/200mA to the charge of the battery.

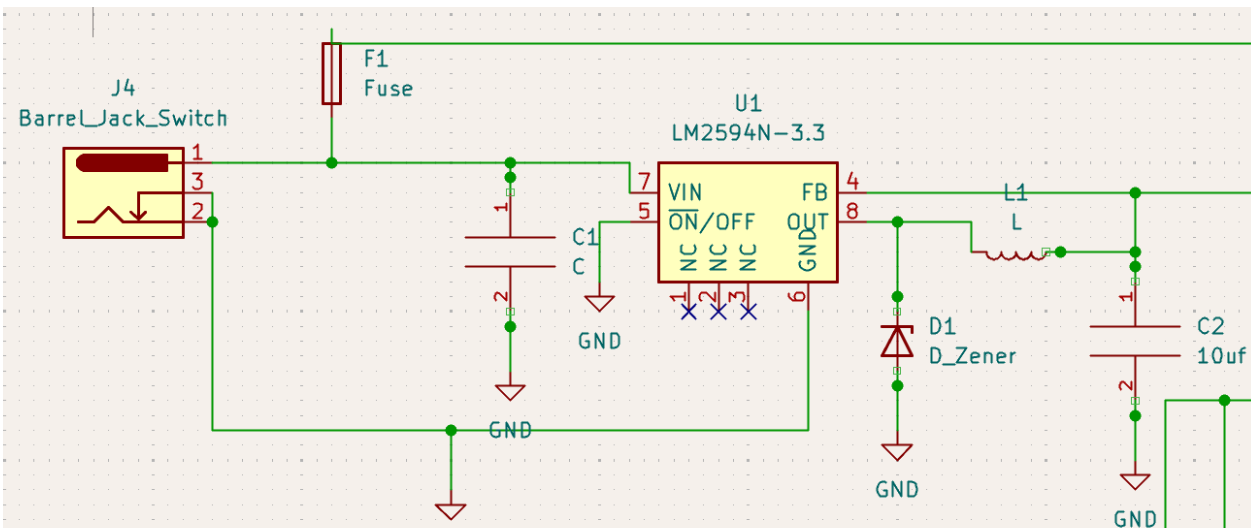

Figure 6. *Power system KiCad schematic*

Requirements	**Verification Procedure**
The battery must be able to provide 12V +/- 0.5V and 3A +/- 0.25A to the barrel jack of the printed circuit board.	- Ensure proper connection between barrel jack and adapter - Utilize test point to probe for incoming power information - Verify that voltage readings are 12V +/- 0.5 V - Verify that current readings are < 3A +/- 0.25A
The buck converter must provide 3.3V +/- 0.2V and at least 500mA of current.	- Ensure proper connection between barrel jack and adapter - Utilize test point to probe buck converter output power information - Verify that the voltage reading is 3.3V +/- 0.2V - Verify that the current reading is at least 500mA
The battery must be able to provide an	- Ensure proper connection between battery and battery load tester.

average of 12V +/- 0.5V for a minimum of 1 hour. Current may vary.	- Run load test using 12V and 3A load for 60 minutes - Verify that voltage remains above 11.5V for the duration of the test

Table 1. *Requirements and Verifications of Power Subsystem*

2.3.2 Control Subsystem

The control subsystem is responsible for providing the motors with the 12V power supply needed to run them as well as the information for how the motors should be moving. This subsystem consists of the h-bridges that are used to control the movement and speed of the rotating and tilting motors. Additionally, the microcontroller can be considered to be part of the control subsystem as it provides the data for the h-bridge to use to allow for movement of the system. The microcontroller, being the “brains” of the system, also takes input from the photodiode array, making it included in the sensing subsystem as well. Connections for the microcontroller are shown in Figure 7 below.

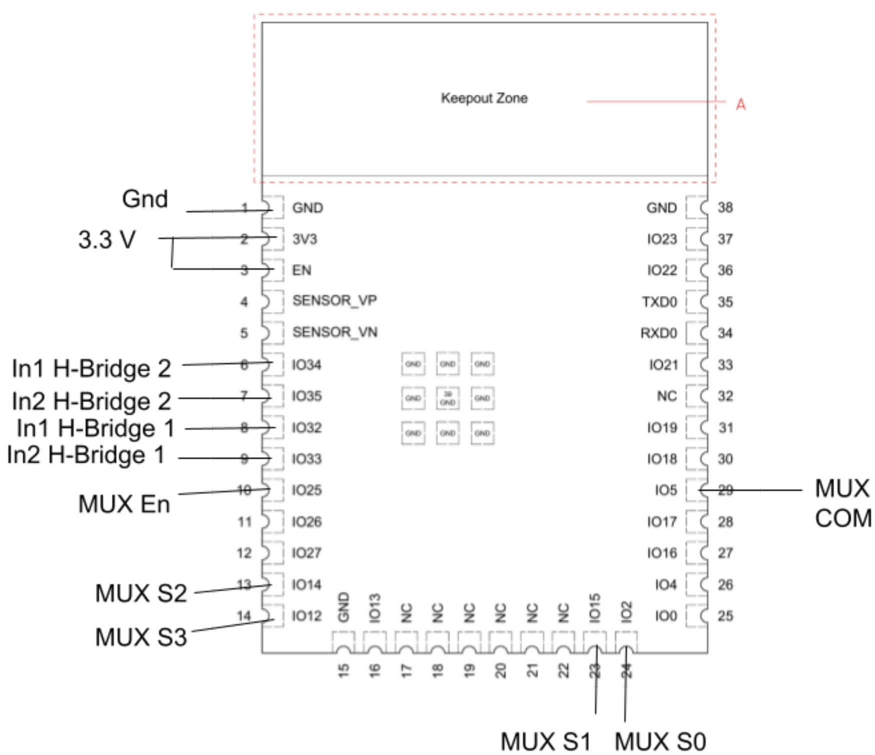

Figure 7. *Microcontroller Connections*

There is one fuse placed between the positive power output of the h-bridges and the motor-to-circuit-board connection points. This is to limit overcurrent damage to the motors or the printed circuit board, should an abnormally large amount of torque be applied to the motor. The resistors connected to the h-bridge (ISEN), are used to control the maximum current output to the motors. With the VREF (reference voltage) of 3.3V as this is what is utilized on most of the board, the tripping current is set by I_{TRIP} = VREF / (10 * R_{ISEN}). As we want the motors to have a maximum current pull of 1.3A as specified by the datasheet, this gives us R_{ISEN} = 0.25 Ω. The motor voltage (VM) is then connected to the 12V source on the board as this is the required voltage for the motors as specified in the datasheet.

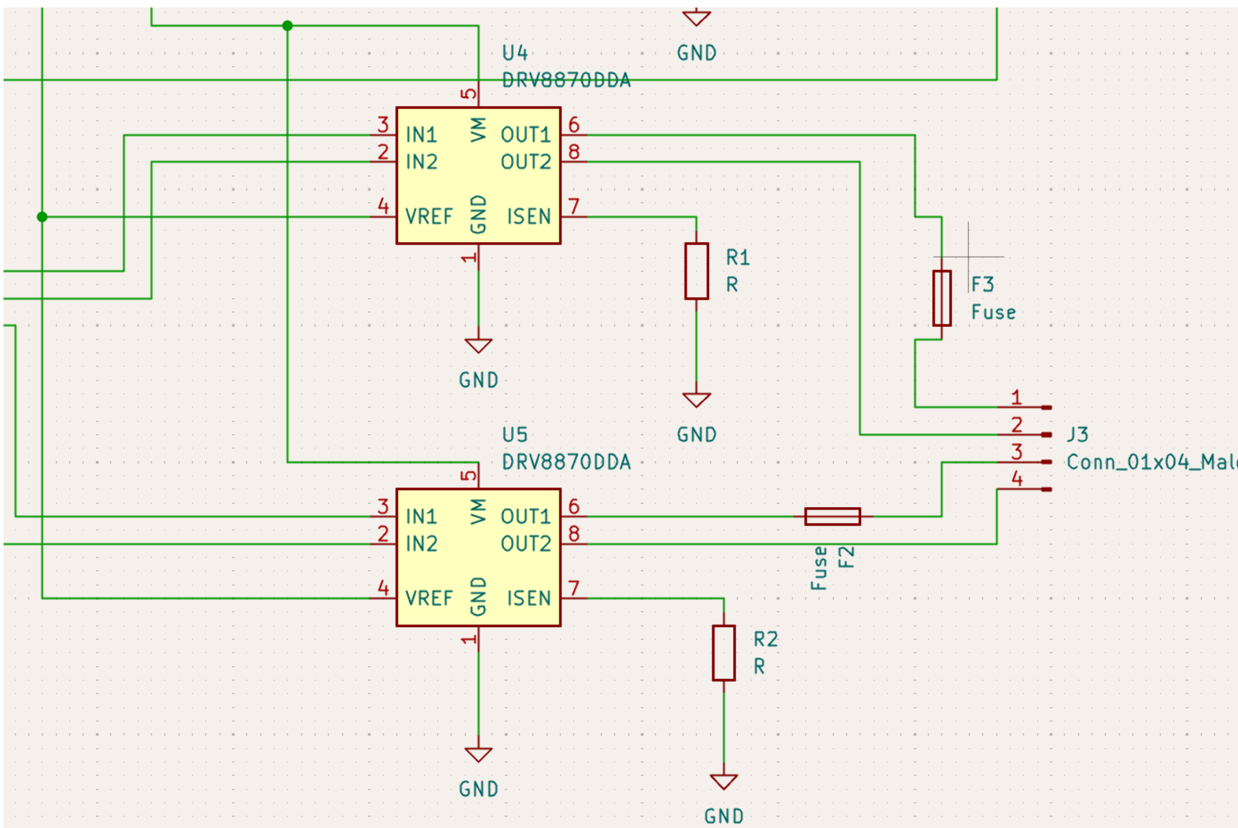

Figure 8. *Control System KiCad Schematic*

Requirements	**Verification Procedure**
H-Bridges are able to move motors in the forward and reverse	- Program the microcontroller such that a signal is sent to each h-bridge to rotate the motors forward at 10rpm in order to confirm motor speed

directions based on signals given from the microcontroller.	- Run said program on the microcontroller and verify that motors are running at 10rpm +/- 1rpm in the forward direction - Once prior verification is complete, program the microcontroller such that a signal is sent to each h-bridge to rotate the motors backwards at 10rpm - Run backwards movement program on the microcontroller and verify that both motors are running at 10rpm +/- 1rpm in the reverse direction
H-Bridges must be able to move the motors ½ rotation within 5°.	- Using a marker, mark a portion of the outer edge of the motor axes in order to track rotation - Ensure proper connection to motors from h-bridges and verify movement functionality prior to testing rotation accuracy - Program the microcontroller to tell the h-bridges to rotate 180° - Ensure that starting position is at a stationary point of measurement - the edge of a table or marked surface - Rotate the motors 180° and use a protractor to verify rotation accuracy to within 5° (+/- 2.5°) of supposed position
The H-Bridges limit the amount of current supplied to the motors based on values of VREF and R_{ISEN}.	- Ensure proper functionality of motors and h-bridges prior to verification of current limitation - Probe motor leads/test point to monitor current running to/from motors - Supply motors with 12V, 1A power supply from h-bridges - Either a) manually add torque to the motor to ensure no overcurrent is detected or b) send the h-bridge a signal to send 2A of current to each motor from the motorcontroller - Verify that current does not exceed maximum rating of 1.3A to each motor

Table 2. *Requirements and Verifications of Control Subsystem*

2.3.3 Sensing Subsystem

The sensing subsystem consists of the photodiodes on the umbrella and the software required to compare the received data. The photodiodes will be organized on the umbrella as seen in Figure 2 and will have an attached resistor in order to limit the voltage and current being input to the microcontroller. Limiting the voltage ensures that it falls within a range accepted by the microcontroller and limiting the current ensures a safer product. The initial setup used the BPW34 silicon PIN photodiodes. Despite reverse biasing them in an attempt to increase sensitivity, we may move to the VTP1188SH silicon photodiode which has a clear lens that makes it more sensitive. The photodiodes will be fed into a 16:1 multiplexer on the PCB that the software will use to compare two photodiodes on opposite sides in order to determine which motor to move and when. Currently, the software is being developed on the ESP-IDF extension in VS code in order to use C to develop the necessary comparator. A maximum voltage output will be determined in order to compare the current position of the center diode to the most optimal position. The center diode will be polled after every move to see if it is within a specific range of that maximum voltage output i.e. the most optimal output. If a move is required, then all the photodiodes will be polled in order to determine which two photodiodes, on opposite sides, have the largest voltage difference. That will then send a signal to the motors in order to move the umbrella toward the photodiode with the higher voltage. There will be a built-in counter that tracks which two photodiodes were used to move the umbrella and if it reaches three in a row of the same two, there will be an override that counts the umbrella as adjusted in order to avoid the motors making endless, small adjustments. The code will then be flashed onto the microcontroller, giving the PCB fully autonomous control of the system.

Requirements	**Verification Procedure**
LEDs on opposite sides detect a difference of 0.02V with a difference in intensity of 30 lumens.	- Manually illuminate the photodiodes in a dark room and record the output of the photodiodes prior to connecting them to the PCB. - Run the same test in a lit room and ensure the same sensitivity is maintained. - Probe the outputs of the PCB to ensure that the corresponding changes match the difference in intensity detected.
PDs/system have a tolerance that determines whether “best case” scenario was reached.	- Adjust the connected resistor during manual testing so the voltage output at the same intensity is as close as possible for each photodiode. - The system does not poll the photodiodes when the center photodiode is within 0.01 of maximum recorded voltage output. - Add an LED that goes high when within the allowed range of difference to explain why motors are not moving.
The system does not adjust more than 3	- Ensure that all but one pair of photodiodes are completely blocked from all incident light

times in a row for the same photodiode pair.	- Take a 30 lumen device (such as a phone flashlight), and illuminate one half of the photodiode pair - Verify that the control subsystem effectively moves the umbrella based on the incident light - Take the same 30 lumen device and illuminate the other half of the photodiode pair (the photodiode opposite the one previously used) - Verify that the control subsystem effectively moves the umbrella based on the incident light - Repeat steps 2 - 4 - Verify that the control subsystem **DOES NOT** make any changes to the umbrella state as this will be comparing the same photodiodes more than 3 times and making adjustments accordingly, which is **NOT** desired

Table 3. *Requirements and Verifications of Sensing Subsystem*

2.3.4 Display Subsystem

The display system will provide the user with an interactive component in which they can manually override the photodiode input to adjust the umbrella position. This feature will be implemented using the microcontrollers wifi capabilities, allowing the user to connect to the network from their personal device via a web browser. With this design in mind, there is no physical component to be completed to implement this subsystem, but rather the simple design of the user interface that is desired. This will include one control for the lower (rotation) motor, and one control for the upper (tilt) motor, allowing the user to move the umbrella to any position within the physical constraints of the device (180° for the lower motor, 45° for the upper motor). There will also need to be a selection option so the system knows whether to operate in autonomy, or to take instructions from the display system. This feature will need to be toggled when the user wants to manually override the photodiode array and then toggled again when the user wants the umbrella to behave autonomously.

Requirements	**Verification Procedure**
The user can successfully gain control of the system, overriding any information coming from the photodiodes.	- Ensure proper functionality of the autonomous capabilities of the system prior to performing this test - Have the user toggle the manual override - Use a 30 lumen source (phone flashlight) to shine over one photodiode, and ensure no movements are made by

	the system - Utilize the controls to move the rotation motor around the 180° range of freedom - Utilize the controls to move the tilting motor to its 45° physical limit - Ensure motor movements are consistent with desired input from the user
Data from the physical system is transmitted in no longer than 30ms to the display system/web browser.	- Read logs from ESP32 to ensure data is transmitted often enough. - Adjust light source manually (phone flashlight) and ensure that no noticeable delay occurs in updating the display system.

Table 5. *Requirements and Verifications of Display Subsystem*

2.4 Tolerance Analysis

The sensitivity of the photodiodes is critical to the success of this project and poses the most difficulty. We want to be able to detect as much change in intensity as possible, allowing us to move the umbrella with a high level of accuracy and give us enough of a buffer so that when comparing two photodiodes we can declare a “best case” where they are equal within a reasonable range.

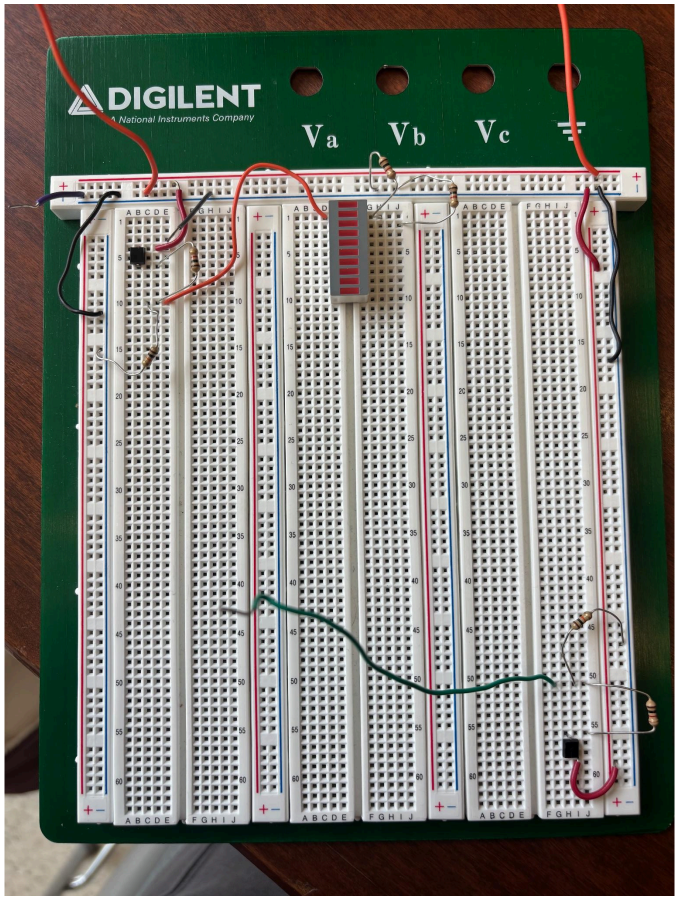

Figure 9. *Experiment setup on breadboard*

Our experiment compared three situations. Since the experiment was conducted in the ECE atrium with a phone flashlight, we expect the results to be similar to the real world conditions, however, the outdoor use case should have higher sensitivity as Si photodiodes detect into the UV range. We put two photodiodes on opposite corners of our largest breadboard in an attempt to record different intensities while still being able to measure the output with an ADALM2000. The photodiodes were reverse biased with 5V so the output could be compared with the datasheet and a current-intensity relationship could be confirmed. The photodiodes then led to a voltage divider with a 10kΩ and 1kΩ resistor in order to move the voltage into a range that could be measured since the maximum current output of the BPW34 photodiode is 600 µA (when it is experiencing $10^{3.8}$ lux). The 1kΩ resistor stabilized the current so that the current voltage across the 10kΩ resistor could be measured. The setup can be seen in Figure 9.

The first situation was a control, with light only from the environment. We wanted to see if the photodiodes would detect the exact amount of light to establish a baseline output. The results of this experiment can be seen in row 1 of Table 6. This control confirmed that the photodiodes were equally sensitive to the environment which allows us to directly compare the values without an offset. The datasheet [5] includes plots to relate current and intensity incident on the photodiode. Using Ohm's Law with the voltage we read and the resistor value, we get a current of 0.3μA. The information from the datasheet equates this current to approximately 0 intensity incident on the photodiode.

Figure 10. *Situation 2 setup*

The second situation placed a phone flashlight approximately 5 cm above the table to detect differences with light directly shining on the photodiodes. The breadboard is around 1 cm tall, so the flashlight was 4 cm off the photodiode. This setup is shown in Figure 10. To ensure accurate data, we were careful to move any wires and other shadow-casting objects out of the way of the photodiode. The voltage across each photodiode was then measured in two cases. The first case is having the flashlight over photodiode 1, in the top left corner of Figure 9. The second case is having the flashlight over photodiode 2, in the bottom right corner of Figure 9. The results of each of these cases are shown in rows 2 and 3 of Table 6.

Again using Ohm's Law to find the current through the photodiodes, we get 0.8μA. This equates to about 10 lux incident on the photodiode. With a sensitive area of 7.5 mm^2 that equates to 75μ lumens.

Figure 11. *Situation 3 setup*

The third setup placed the phone flashlight even closer to the photodiodes. The phone was about 2.5 cm away from the table, so the light ended up being 1 cm above the photodiode. The setup was nearly identical to situation 2. The results for both cases (light over photodiodes 1 and 2, respectively) are shown in rows 4 and 5 of Table 6.

For photodiode 1, Ohm's Law results in 8.7μA. According to the data sheet, this equates to around 180 lux incident on the photodiode. With a sensitive area of 7.5 mm^2 that equates to 180μ lumens. For photodiode 2, Ohm's Law results in 9.2μA. According to the data sheet, this equates to around 190 lux incident on the photodiode. With a sensitive area of 7.5 mm^2 that equates to 190µ lumens.

Experiment	**Photodiode 1**	**Photodiode 2**
Situation 1 (Control)	-0.003 V	-0.003 V
Situation 2 (4 cm, flashlight on photodiode 1)	0.008 V	-0.005 V
Situation 2 (4 cm, flashlight on photodiode 2)	-0.003 V	0.008 V
Situation 3 (1 cm, flashlight on photodiode 1)	0.087 V	-0.005 V
Situation 3 (1 cm, flashlight on photodiode 2)	-0.003 V	0.092 V

Table 6. *Results of the experiment*

The first set up detected 0 lumens and since the standard office room outputs 300-500 lux [4], we see that the BWP34 photodiode is not sensitive enough to detect that low of an intensity. The second and third set up established the sensitivity for the two photodiodes. Photodiode 1 has a 0.079 V difference when there is a 170 lux change. Photodiode 2 has a 0.084 V difference when there is a 180 lux change. On an overcast day there are about 1000 lux incident on the ground [5]. Full daylight has anywhere between 10,000 to 25,000 lux incident and direct sunlight has 32,000-100,000 lux incident. Based on our experiment, the photodiodes would produce, on average, approximately 0.5 V difference for every difference of 1000 lux. This is reasonable to detect with the photodiodes, as shown in the experiments above. A tolerance of +/- 0.05 V allows us to still accurately track the Sun, while avoiding small, repetitive movements from the motors.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Graduates from the University of Illinois ECE department with Electrical Engineering degrees make on average $90,000 a year [3]. There are approximately 260 working days in a year, so this salary is around $45/hour.

Assuming the following for hours:

Electrical Design: 30 hours

Mechanical Manufacturing: 10 hours

Electrical Manufacturing: 20 hours

Software: 30 hours

Total (per person) = $45 * 2.5 * (30+10+20+30) = $10,125.00

3.1.2 Parts

Description	Manufacturer	Part Number	Quantity	Unit Cost	Total Cost
Umbrella	N/A	N/A	1	$0	$0
Motors	Fafeicy	Fafeicyogdbg2c9up-01	2	$19.28	$38.56
Battery	GoldenMate	CRIUS7 - IP67 Waterproof	1	$25.99	$25.99
Solar Cells	SuniAde	634562712844	1 (pack of 10)	$20.99	$20.99
Wall to Barrel Jack Adapter	XP-Power	AMF18US24	1	$14.95	$14.95
Microcontroller	Espressif	ESP32-WROOM-32E-N4	1	$4.84	$4.84
Buck Converter	Texas Instruments	LM2594	1	$1.90	$1.90

USB-to-UART Converter	Silicon Labs	CP2102N	1	$3.52	$3.52
Motor Controller	Texas Instruments	DRV88703.6-A	2	$0.77	$1.54
16:1 MUX	Texas Instruments	CD74HC4067	1	$0.73	$0.73
Photodiodes (TBD): BPW34 VTP1188SH	 Vishay DigiKey	 PD-6 same	 17 17	 $0.43 $3.58	 $7.31 $60.86
Reset/Control Button	Omron	B3F	1	$0.24	$0.24

3.1.3 Total

Student Labor	Parts	Machine Shop Labor	Total
3*10,125 = $30,375	$120.57 - $174.12	20 hours	$30,495.57 - $30,549.12

3.2 Schedule

Week	**Task(s)**
10/6	Complete breadboard design (Megan) Complete breadboard demo (all) Teamwork evaluation 1 (all) PCB order complete (Sarah) Write design document (Dora, all) Receive motors and deliver parts to machine shop (Dora) Order PCB parts (Sarah) Select all parts (all)
10/13	Order battery and solar cells (Dora) Begin writing software for and testing motors Create test plan for when PCBs arrive (Sarah) Pick up all self service parts (all) Have functional breadboard with dev board implemented (all)
10/20	Work on any PCB redesigns for third PCB round (all) Write main comparator -> motor movement software
10/27	Complete breadboard design 2 (all) Combine comparator and motor software and test Assemble sensors on umbrella Implement solar cells

11/3	Third PCB Order (Sarah) Individual progress reports (all) Begin testing for all requirements/verifications listed above (all)
11/10	Fourth PCB Order (Sarah) Complete testing (all) Prepare for mock demos (all)
11/17	Mock Demos Team contract assessment
11/24	Fall Break Work on final presentation Work on final paper
12/1	Final Demo Present Mock Presentation Write Final Paper
12/8	Present Final Presentation Submit Final Paper Turn in lab notebook Lab Checkout

4. Discussion of Ethics and Safety

4.1 Ethics

The only ethical issue that could arise from this project is IEEE I.1 and II.9 [2], both in accordance with keeping the safety of others at the forefront of the mind. To ensure no ethical breaches we will ensure maximal safety precautions. Our main safety concerns are mechanical, and we will therefore be assisted in upholding the safety of the device by speaking with the machine shop and taking into account the expertise they have in mechanical design. We are mainly considering harsh motions of the umbrella, whether that be closing unexpectedly or moving too quickly. These can be worked on in software and ensuring the motor spins at a reasonable pace as well as integrating a warning light to show the users that the umbrella is about to turn so they can be best prepared. Another concern in ensuring that the holding torque of the tilt motor is high enough to avoid the umbrella falling. To combat this we will include mechanical stops alongside our software cues to be positive there is no possibility of the umbrella falling on the user.

Additionally, since our project is meant to be used in the Sun we wanted to consider the possibility of overheating. We will consider all of our subsystems individually for this. We have no concern with the solar cells or photodiodes for overheating. These components are meant to be in the Sun, and the photodiodes will be protected from overexposure with their enclosures. The rest of the components are susceptible to overheating, however we will ensure that they are shaded by the umbrella and have additional software to ensure that the system shuts down or gives the user a warning when the components are close to overheating.

Overall, we believe that through a few extra components we can keep the overall project entirely safe and ethical under all circumstances.

4.2 Safety

Some safety concerns that arise from this project include sudden mechanical failure of either motor, unexpected movements that arise from the motors, as well as the battery overheating under extreme conditions. To mitigate these concerns, mechanical stops will be included in the design such that should a motor fail to hold its position, the mechanical stop will prevent injury to users. Additionally, a blinking LED will be implemented such that any individual in the surrounding area of the umbrella will be alerted to the upcoming movements/adjustments that the umbrella will be making in order to provide optimal shade. Finally, in order to ensure the battery does not overheat, there is a battery management system (BMS) within the product which protects against over-current, overcharge, over-discharge, over-temperature, etc. The lowest temperature limit for the battery is under storage, at 112° for the upper limit. With this, there will be signage on the product to notify the user/owner of storage conditions, giving them information on when to relocate the product to a controller environment.

For further safety enforcement of the motor usage, there are fuses within the printed circuit board that are meant to stop overcurrent damage from being applied to both the circuit board and the motors themselves. There is one fuse at the main input for our 12V supply, ensuring that the power draw from the battery is not exceeding what is necessary for the system to function. There are two additional fuses between the h-bridges and the motors to ensure that the motors don’t draw too much current under a given torque, ensuring safety of the system and the user.

5. References

[1] Walmart, https://www.walmart.com/ip/Yangming-9FT-Outdoor-Patio-Umbrella-Push-Button-Tilt-Crank-Handle-Market-8-Sturdy-Ribs-UV-Protection-Waterproof-Khaki/671393063?wmlspartner=wlpa&selectedSellerId=101468352&gclsrc=aw.ds&&adid=22222222227671393063_101468352_192691468748_22921905482&wl0=&wl1=g&wl2=c&wl3=770605736366&wl4=pla-2299359008581&wl5=9022196&wl6=&wl7=&wl8=&wl9=pla&wl10=5290415022&wl11=online&wl12=671393063_101468352&veh=sem&gad_source=1&gad_campaignid=22921905482&gbraid=0AAAAADmfBIqfnnqjipnSWJ5p7Ic67D3wd&gclid=CjwKCAjwz5nGBhBBEiwA-W6XRJVlvl45nD90VPJDc8fhZLazrin2bPrSFm42P-5igc3oLg6iz7DtvxoCm9wQAvD_BwE (accessed Oct. 13, 2025).

[2] "IEEE code of ethics | IEEE," IEEE, https://www.ieee.org/about/corporate/governance/p7-8 (accessed Oct. 14, 2025).

[3] Grainger Engineering Office of Marketing and Communications, "Salary averages," Illinois, https://ece.illinois.edu/admissions/why-ece/salary-averages (accessed Oct. 13, 2025).

[4] "Lux," Wikipedia, https://en.wikipedia.org/wiki/Lux#:~:text=Table_title:%20Illuminance%20Table_content:%20header:%20%7C%20Illuminance%20(lux),%7C%20Surfaces%20illuminated%20by:%20Direct%20sunlight%20%7C (accessed Oct. 13, 2025).

[5] "BPW34," Vishay, https://www.vishay.com/docs/81521/bpw34.pdf (accessed Oct. 14, 2025).

5.1 Datasheets

Components (Links embedded):

- Battery
- Solar Cell
- 16:1 MUX
- Motor Controller
- Microcontroller
- Buck Converter
- USB-to-UART

- Push Button
- Motors
- Wall to Barrel Jack