SUN TRACKING SOLAR PANEL

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Final Report for ECE 445, Senior Design, Fall 2017

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13 December 2017

Project No. 35

Abstract

The Sun Tracking Solar System aligns itself with the brightest source of light that is incident with the system. Beyond this motion, the system is also able to reset to a set starting point where it rests until a light threshold is met and it begins to align itself again. The system is also able to store the energy converted from the mounted solar panel in a battery. The battery will be used to power the tracking and movement components of the system.

We built a functioning system through a breadboard that tracked the brightest point. However, we were not able to complete the entire system off the breadboard as our final PCB design malfunctioned. Our tracking system was successful in finding the brightest point and adapting when altered.

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1. Introduction

At the onset of this project, it was our hope to develop a system to efficiently track the sun in order to maximize the energy conversion through a PV solar panel. The project was initially intended to power an off-grid street-light, but we have since realized that this project has much more potential. If the product is slightly adapted from the form we have created, it could be a low-cost solution for greater solar energy yield.

This particular idea was one of many that stemmed from an original proposal made by Professor Karl Reinhard. His intention was to build a streetlight that could be completely self-sustained off of the grid. As the idea matured into actual projects, we decided that it made more sense for us to develop a self-sustained component that could be integrated to the project but that could also operate on it own.

With that in mind we developed three high level functions that we wanted to accomplish by the end of the course.

1) Using the Spherical coordinate system, the solar panel mount will rotate from 165 degrees to 15 degrees along the azimuthal angle and will also tilt from -65 degrees to -20 degrees along the polar angle.
2) The photosensing unit will be oriented to track the sun both East to West and North to South. The unit will provide feedback which will be used to control motor movement. Included in this will be a dusk-to-dawn reset, triggered when the unit reads no light.
3) The battery must be sized to provide power to our system for at least 48 hours.

This report will detail the process our team underwent to create this final product. It details our methodology throughout the course of the semester, as well as give a review of the building and testing phases, successes and challenges, future work, and, finally, our results. Ultimately, we were able to develop a prototype that was able to track the brightest incident source.

2 Design

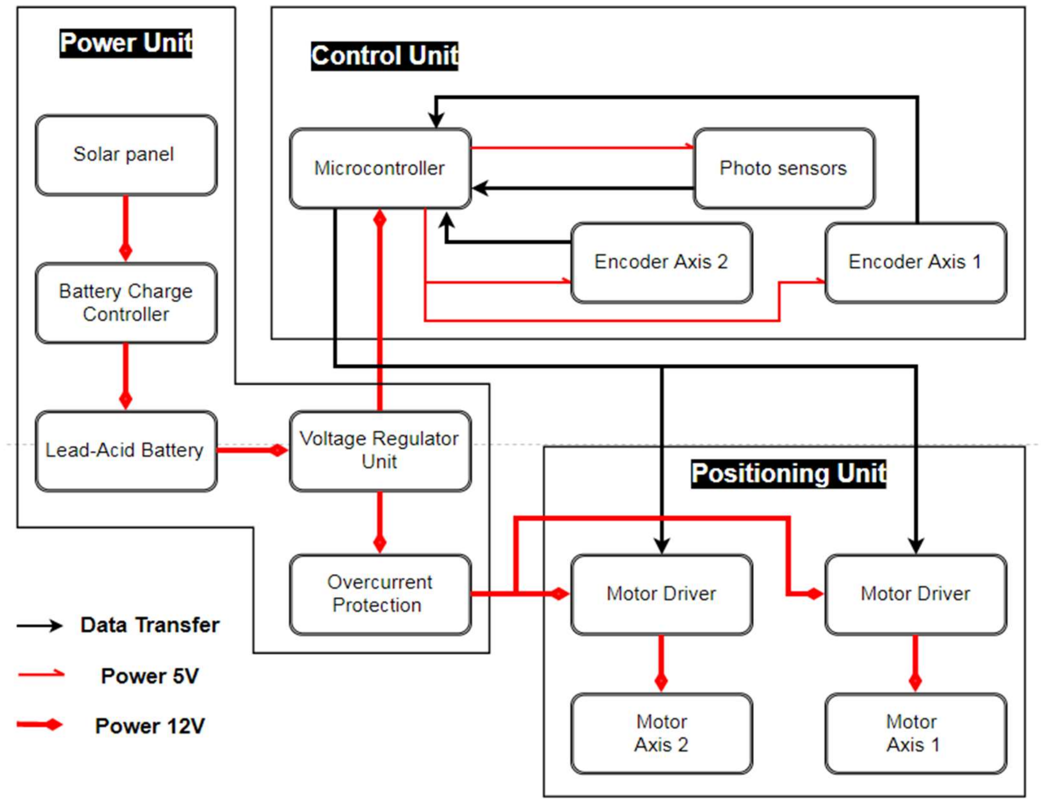

Figure 1: Block Diagram for the Sun Tracking Solar System.

We required three units to operate the Sun Tracking Solar Panel: a power unit, control unit, and a positioning unit. This is depicted in Figure 1.

The power unit ensures that the system can power the control unit, positioning unit, and streetlight for two full days with an average voltage of 12V. It consists of a solar panel used for generation, a lead-acid battery used for energy storage, and a lead-acid charger used to protect the battery.

The control unit contains photosensors, a microcontroller, two encoders, and two motor drivers. The photo sensors are oriented on the solar panel mounting to find the relative position of the sun on two axes. The microcontroller will process the information from the sensors and will send information to the positioning unit to adjust the panel accordingly. The motor drivers will control the direction of the motors used in the positioning unit. The control unit also uses encoders to provide the microcontroller with feedback of the current position of the panel, both tilt and azimuth angles. This will provide the microcontroller with important position information required to implement our tracking algorithm.

Lastly, the positioning unit takes the information from the control unit and moves two motors to adjust the physical position of the solar panel mount to point at the brightest point in the sky.

2.1 Solar Panel

A solar panel was necessary to develop a complete system; as we intended this product to run independently long term. The solar panel wattage and physical footprint were the two options that we could choose when considering solar panels.

In order to save on the overall cost of the project, we opted to recycle a solar panel for our project. Through the help of our sponsor, we were able to find a few solar panels that were made available for us to use. One of the panels was rated at 20W and the others were rated at 100W. We had initially decided to use the smallest power panel possible in order to keep the overall weight and size of the project low; however, once we started to consider the electrical load of the motors and the light bulb we realized that the size of the battery could not be sustained by the 20W panel. Therefore, we decided to go with one of the 100W panels.

The footprint was a decision between a narrow panel or a wider panel, both of the same area. We decided that the thicker and shorter panel would be less dependent on the angle of incidence, which would allow for a more energy efficient design. This is because the panel would not have to be moved as often and the energy used by the motors would be mitigated.

2.2 Solar Battery Charge Controller

The solar battery charge controller is the component in our circuit that regulates the energy transfer between the solar panel and the battery. We decided to include this intermediary step between the panel and the battery in order to maintain life of the battery and the safety of the system. The battery is inherently a very dangerous component and when improperly maintained it can cause physical or environmental damage. Note, Appendix C includes the lead-acid battery standard operating procedure, written to be set as a simple safety protocol for future projects. With safety as our highest concern, we considered which of the off-the-shelf charge controllers would be the safest weatherproof option, while still meeting our system needs.

In terms of safety, we wanted to find a charge controller that was designed specifically for solar applications in order to prevent any unforeseen issues that might result in damage. In doing so, we found that there were two primary types to choose from: controllers that could charge lead-acid batteries and advanced controllers that could manage both lead-acid and lithium-ion batteries. The biggest differences between the two options being the number of available charging regions as well as the cost. As this decision might also decide our choice of battery, we decided to go with the safer and most common option for solar application. The decision we made was to use a lead-acid battery with a dedicated lead-acid battery, specifically, charge controller.

Narrowing down the list, we had to decide on the brand, operation, and on the weatherproofing design. Originally, we decided to go with a Steca-Solsum [13] [14] because of its additional option to disconnect the load once the current draw reached 6A, but because of shipping delays and later noted poor waterproof design for interconnectors, we went with a Morningstar

SunKeeper[15]. This unit is all-around waterproof with similar functionality to the Steca, except for the load disconnect feature. This particular model was attractive because of its high customer approval ratings and its simple waterproof design.

From there, all that we had left to choose was the specific sizing of the unit to meet the needs of our system. We decided on the Morningstar Sunkeeper SK-6 because its rating matched or exceeded our needs and any higher rated option would have been unnecessary. Note that a simple schematic of the battery charge controller can be seen in Appendix B, Figure 7. Also note that all figures and tables not directly sourced in the text can be found in Appendix B.

2.3 Lead-Acid Battery

In order for our system to run off of its own power, we needed to include some sort of energy storage. We decided that an AGM (Absorbent Glass Mat) lead-acid battery was the best option for this project. Ultimately, we decided on the SunXtender PVX-340T [23]. The reasons that we went with this battery is the type of battery, its nominal voltage, and its energy capacity.

The first decision that was made when deciding the battery was the choice between lithium-ion and lead-acid. We had originally considered lithium-ion because of the size and weight of the battery and the ability to frequently discharge to low energy storage. We then decided that lead-acid would make more sense for our project. The problems we came to have with lithium-ion were primarily safety-based. It is true that there is some inherent danger when working with a battery, however, we came to realize that lithium-ion batteries were more dangerous because of the higher risk of explosion and fire. We also felt that the lead-acid battery would be safer for our own personal testing because they are more forgiving when it comes to overcharging. The chemistry type, AGM, was decided in order to mitigate the potential for battery acid leaks. The AGM chemistry stores the energy in a gel as opposed to other chemistries, which store the energy in a liquid. The gel allows for easier mobility and placement of these batteries because there is a much lower risk of leaks. The last decision we made was to choose a battery that could handle deep discharge cycles. This means that the battery can discharge to much lower amounts without any serious damage to the battery. We wanted a battery of this type because of the application we intended to use it for. The overall application of the project is to enable the use of a standalone streetlight, as well as other integrated parts, to run for as little as two days under poor charging conditions. That means that the battery may run below the recommended 50% energy capacity which in the long run damages the internal chemistry and may lead to leaks or fire. In order to mitigate that, as well as other dangers, we choose a deep cycle, AGM, lead-acid battery. Note Appendix C for the written standard operating procedure for the battery.

We decided early on to run our system at a nominal voltage of 12V. This decision was made because it was the rated voltage for most of the motors we were considering and, in order to mitigate losses in conversion, we decided to use a 12V battery directly.

This particular model of battery is intended to provide 37Ah over the course of 48 hours. We estimated the size of the battery to be at least 30Ah using the following table and equations.

Table 1 Battery Sizing Chart

Load	**Quantity = Q**	**Avg. Power [W] = P**	**Use time [Hours/day] = T**	**Energy per day [Wh/day] = E**
Charge Controller	1	.048	24	1.152
Microcontroller	1	.034	24	.81
Photoresistors	5	.028	.267	.007
LED Street Light	1	33	5	165
Encoder	2	.04	.267	.011
Motor (1 - Tilt)	1	16.8	.017	.286
Motor (2 - Azimuth)	1	6	.25	1.5
Total Energy per day = 168.77 Wh/day Approximate 180 Wh/day				

The average power (P) is found by multiplying the average voltage (V), average current (I), and quantity (Q) of each component:

$$P = VIQ \tag{1}$$

The energy used per day (E) is found by multiplying the average power (P) by the time used per day (T):

$$E = PT \tag{2}$$

The time the equipment is used per day is estimated to match what we might expect for a full day of movement.

The rating used for batteries is the Amp-Hour. We can convert Watt-hours to Amp-hours by dividing by the nominal voltage (12V).

$$\frac{180 * 2}{12} = 30Ah \tag{3}$$

Notice we multiply the energy capacity by 2. This is done because the recommended depth of discharge is 50%; therefore, we can only use half of the total energy stored. At a minimum, we then recommended 30Ah for two days discharge rate. Our sponsor decided to purchase a 37Ah battery upon the recommendation of our team as well as the other project teams.

2.4 Voltage Regulators

Our design required stepping down the voltage from the battery for our motors and microcontroller. We considered using a direct-current to direct-current (DC/DC) converter or a voltage regulator. Although DC/DC converters are more efficient at stepping down voltages, our team lacked the experience we felt was necessary for a safe execution of the project. Therefore, we chose to use a voltage regulator because of the lower risk to our safety and the completion of the project within the limited time we had. Two voltage regulators regulated the battery voltage of 15V to supply the microcontroller with 5V and the motors with 12V. The 12V voltage regulator needed to carry a peak current of 2A to power our motors. The schematic is shown in Appendix B, Figure 8.

The linear voltage regulators required two resistors to set the output voltage. These resistance values were calculated using the following equation [26]:

$$V_0 = V_{Ref}\left(1 + \frac{R_2}{R_1}\right) \tag{4}$$

where V_o is the desired output voltage, V_{Ref} is 1.25V, and R_1 is 120Ω. We then calculated R_2 for output voltages of 5V and 12V:

Table 1. Resistance Values of Voltage Regulators

Output Voltage (V)	R_1 (Ω)	R_2 (Ω)	Chosen R_2 (Ω)
5	120	360	400
12	120	1032	1000

2.5 Over-Current Circuit

Our design included motor protection to increase the lifespan of the motors. In our original design, we included an under-voltage circuit with the intention to cut-off the voltage to our motors when it dropped below a certain level. However, we realized that the speed of our motors is proportional to the voltage, and the current is proportional to the torque. We changed the under-voltage circuit to an over-current circuit. The over-current circuit cuts off the power to the motors when they draw more than 2A. This can occur if our motors require more torque to move. Some scenarios that this could happen in, is attempting to move against the wind or if the mount is physically jammed. Drawing large amounts of current can damage our motors and is a waste of energy. A schematic of circuit is shown in Appendix B, Figure 9.

The 2A is set by a sense resistor. When there is a 100mV drop across the resistor the circuit will cut off [27]. This calls for a .05Ω sense resistor.

2.6 Microcontroller

Our microcontroller is of central importance for the project because it coordinates signals between the encoders, photoresistors and the motor drivers to make the positioning and power units work together. We chose to use an ATMEGA-328P [6] for this project. The main functionalities our microcontroller needed were to be able to:

1) send information to the motor drivers
2) process the analog signals from our photosensors
3) process the digital signals from the encoders

These could be done by the ATMEGA-328P, a microcontroller from the ATMEL series. One of the other reasons we chose this microcontroller is that the Arduino Uno is a widely used microcontroller set. There is plenty of documentation and tutorials available online that showed how to use the different functions of the microcontroller. In addition, the microcontroller was relatively cost effective.

Our final pin mapping for the Arduino Uno included:

1) 5 analog pins being used for the 5 photosensors,
2) 4 digital I/O pins being used for the motor drivers and
3) 2 pins for the azimuthal angle encoders.

The other pins used were the GND and V_{cc} pins for the microcontroller and the analog GND, analog V_{cc} and analog REF pins.

The microcontroller output voltage is capped at 5V. We can supply it 12V, but it only output between 0 and 5 V in the IO pins. It cannot output more than a few milliamperes of current as well. So, we cannot use it to drive a motor.

2.7 Motor Driver

For our project, we needed to use two motor drivers, one for each motor. The motor drivers needed to accept logic signals of 5V since they are being supplied by the microcontroller. It also needed to be able to output a variety of voltages without adversely heating up for testing the speed of the motors. The motor driver L293D [7] from Texas Instruments served our purpose well. It was inexpensive and was able to house the logic and pins needed for two motors on a single chip. This motor driver was able to output voltages between 4.5 and 36V. This was especially beneficial for testing because we were able to make our solar panel move faster or slower accordingly. We could also switch directions on the motor by supplying different logic signals, which switched the motor driver's outputs to move in the opposite direction.

2.8 Motors

We required our design to move the solar panel along two axes of motion. To do this, we considered using step motors, servos, linear actuators, and DC motors; these devices were necessary to move our 16-pound solar panel in a controlled manner. The step motors and servos did not meet this requirement because their output torque was too low. They also required power to hold the solar panel in place when the panel was not moving. Linear actuators did not meet our physical design requirements. We decided to recycle DC motors found in the machine shop. These motors provided enough torque to move the panel and they did not require power to hold the panel in place. Recycling them also lowered the overall cost of the project and is environmentally friendly.

2.9 Photosensor

Our team considered two models of the photosensors. One was a photoresistor type from Adafruit [9] whereas another was a type of an infrared optical sensor from Arrow [8]. After testing both, we found the photoresistor very fit for our purposes as it showed great range of roughly between 0 and 4V; this is an adequate range as we only intend to send 5V to the photosensors. Another issue was that the optical sensor we found from Arrow, was only detecting light of roughly 900nm. This was not useful for our purposes as we needed a sensor that could work with visible light (400nm to 700nm). So, we excluded it from all further testing. The photoresistor we ultimately chose was the PDV-P8001 from Adafruit.

2.10 Encoders

Since we decided to use DC motors for our physical movement, we required a feedback system to monitor the physical location of the mount on both axes. We considered using physical sensors, movement sensors, and encoders. Physical sensors like switches or flex sensors, would allow us to monitor the solar panel only at its maximums by hitting the physical switch mounted on our mount. Movement sensors like gyroscopes and accelerometers, would be difficult to implement because of their unreliability and our lack of experience with these devices. We decided to use encoders because they give feedback based off the rotating shafts of each of the axes.

We also considered different types of encoders: optical, magnetic, and capacitive. Optical encoders use lights and light sensors contained within the encoder. But, this allows them to be prone to dirt and dust, and requires calibration after several years. This would not be ideal for the outdoor applications of our project. Magnetic encoders are more robust, but have lower resolution [25]. We decided to use capacitive encoders because they are resistant to dust and dirt and they have the ability to select the resolution of the device.

Our encoders provide a resolution of .175 degree and was accurate within 5 degrees. We used the following equation to calculate the physical angle:

$$\Theta = \left(\frac{C_{ec}}{N}\right) * 360 \tag{5}$$

where N is the resolution setting of the encoder (2048) and Θ is the physical angle. Calculating for C_{ec} equal to 1, yields a resolution angle of .175 degrees.

$$\Theta = \left(\frac{1}{2048}\right) * 360 = .175^0 \tag{6}$$

3. Design Verification

3.1 Solar Panel

The verification of the solar panel was essentially to ensure that the panel could produce enough power as it is rated. This was done by checking the voltage and current that the panel can produce. We checked that the panel can produce a voltage between 15V and 20V. We also saw that the current generated from the panel could reach upwards of 5A. This means that under normal conditions, the panel is capable of outputting nearly 100W.

3.2 Solar Battery Charge Controller

In order to verify the charge controller, we needed to make sure that it could properly charge the battery. The easiest way to do this was to check what the battery output was when the solar panel input was between 15V and 20V. We noticed that the output was a PWM wave with an amplitude of 15V. This is what we expect to see in this range, notice the waveforms in Appendix B, Figure 15. The PWM wave is how the charge controller is able to reference the current charge of the battery and prevent overcharging.

The second requirement for the charge controller was that it would prevent current from flowing back into the solar panel. If current were to flow back to the panel, it might damage it. This test was done by applying a 12V input to the battery terminal, and the solar terminals were measured. We noted that the voltage stayed relatively close to zero, preventing a backflow of current to the solar panel, this can be seen in Appendix B, Figure 16.

3.3 Lead-Acid Battery

The lead-acid battery is the power source of our project. We were able to verify that it could power our circuit by validating the voltage output and the capacity of charge. In order to verify the voltage output, we checked the open circuit voltage. We verified that the battery did output a nominal voltage of 12V.

We checked the capacity of charge of the battery by assuming that the battery was at half charge, from full, when it reached 12V. We connected the battery to a 1Ω resistor and checked the output voltage every ten minutes for an hour and then once more after five minutes. Using the following equation, we were able to verify the capacity of the battery at a 2-hour discharge rate. Where C, is the capacity in Amp-hours, and t, is the time in hours. We calculated a capacity 26Ah and the rated capacity was 27Ah, see Appendix B, Table 5 for data. We take this to mean that for a 48-hour discharge, we should reach a capacity of approximately 37Ah, the rating designated on the specs sheet, which is greater than our recommended 30Ah [23].

3.4 Voltage Regulators

To certify our voltage regulators, we needed them to regulate the input voltage to the desired output voltage. We provided both voltage regulators input voltages ranging from 0V to 15V and monitored the output using a multimeter. A graph of the output voltage for the 12V voltage regulator is shown in Appendix B, Figure 10. Each voltage regulator regulated the voltage down to the desired output.

For the twelve-volt regulator, we certified that it could carry 2A by using the DC load. Setting the DC load in constant current mode to draw 2A, we monitored the output voltage using a multimeter to ensure there was no voltage dropout.

3.5 Over-Current Circuit

To verify the over-current circuit, we provided 12V to the device and used various power resistors to change the current draw of the circuit. We monitored the output voltage and the timing capacitor of the circuit to tell when the circuit turns off using an oscilloscope. When we used a 6Ω power resistor to force the current above 2A, output voltage fell to zero and the voltage across the timing capacitor was a sawtooth waveform shown in Appendix B, Figure 11. Appendix B, Figure 12 shows the output voltage and current of the over-current circuit as we decrease the resistance.

3.6 Microcontroller

We ran preliminary tests on the microcontroller to ensure it had the functionality to send and receive signals on its digital pins, give out 5V and receive variable voltages on the analog pins. All testing was done using a USB cable and an Arduino Uno R3. Since the testing was done on the Arduino board itself, we ran an additional test to ensure the microcontroller would work on the breadboard without the support of the computer.

The first requirement we created was the ability to send out signals based on the input signals given. For this requirement, we used a microcontroller and the photoresistors to test the light coming out from an LED, this schematic can be seen in Appendix B, Figure 2. The LED is connected to pin 9, which is a digital pin. This outputs a voltage between 0V and 5V, depending on the voltage read by the photoresistor. To regulate the voltage read by the photoresistor, we used a flashlight that was positioned at varying distances.

The next requirement we had was the requirement to ensure we are able to output 5V from the digital pins in the microcontroller, this schematic can be seen in Appendix B, Figure 3. We use a voltmeter to measure the voltage in this procedure. The motor driver cannot accept logic signals below 4.5V; thus, it is pivotal to ensure that 5V can be outputted from the digital pins.

We passed both requirements. As a result, we knew that the microcontroller could have code uploaded to it and processed to have output signals. We also knew the maximum and minimum voltages that it could output. This information was crucial moving forward as we could fully focus on ensuring the code integration logic was completely correct.

3.7 Motor Driver

The motor driver had two main functionalities that enabled it to work for our purposes, our circuit schematics can be found in Appendix B, Figures 4 and 5. First, it should be able to accept input logic and output different voltages based on the input logic. Next, it should be able to move the motor in two different directions, clockwise and counterclockwise. These two functionalities are pivotal in ensuring that the motor driver can work with the inputs from the microcontroller and the outputs being strong enough to power a motor to move in different directions, a table for this control can be found in Appendix B, Figure 6.

3.8 Motors

We started by verifying the characteristics of our motors by comparing the specifications of various motors online. We searched for motors with similar voltage ratings, manufacturer, and style. Appendix B, Figure 13 is a plot using the specifications known about these motors, we estimated the max torque of our motors to be around 800 oz-in and the stalling current to be about 2.6A. Appendix B, Figure 14 is a plot of the current versus torque of our motors. This was done by lifting various weights like a pulley and measuring the current of the motors. This allowed us to estimate the torque required to move the panel by measuring the motor's current draw.

We also verified that the motors do not require more than 5A to move the solar panel. We did this by using a power supply to move the motors and monitoring the current draw of the motors. We found that the motors max current was around 1.1A.

3.9 Photosensors

After we decided on using the PDV-P8001, we tested out various configurations to use the sensor. One of the problems we encountered was that after a certain amount of sunlight, we were unable to detect any more sunlight because the resolution of the resistor was not clear enough. As a result, we decided to test the photoresistors using a black box with a small slit to allow a limited amount of sunlight through to the sensor. This was to ensure that we could distinguish between the sunlight levels at different times of the day. Otherwise, the sensors were too sensitive and would always read a high value. We got a maximum voltage of 4.5V from any sensor at a peak sunlight rating, and a minimum of 0V in darkness.

3.10 Encoders

Once the encoders were implemented into the systems and code, we verified the accuracy of them. This was done by using a phone protractor app to find the angle of our mount. Appendix B, Table 6 compares the physical angle to the output angle calculated within the code.

4. Costs

4.1 Parts

Table 2 Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Solar Panel	Renogy	$129.99	$129.99	Free
Battery Charge Controller	Morningstar Corporation	$52.00	$52.00	$52.00
Battery	SunXtender Solar Batteries	$189.94	$189.94	$189.94
Photoresistors	Adafruit	$2.22	$22.22	$22.22
Voltage Regulator	STMicroelectronics	$1.46	$0.729	$2.92
Overcurrent IC	Linear Technology	$2.50	$2.10	$2.50
Encoders	CUI Inc.	$23.63	$20.475	$47.26
1kΩ Resistors	Stackpole Electronics Inc.	$0.10	$0.00729	$0.10
120Ω Resistors	Stackpole Electronics Inc.	$0.10	$0.00729	$0.10
400Ω Resistors	Stackpole Electronics Inc.	$0.10	$0.00729	$0.10
100µF Capacitor	Nichicon	$0.4538	$0.1146	$1.82
0.22µF Capacitor	Nichicon	$0.2175	$0.1782	$0.22
Microcontroller	Atmel	$29.95	$29.95	$89.85
Motor	Pittman	$117.50	$94.60	Free
Motor Driver	Texas Instruments	$3.91	$19.45	$19.45
Zener Diode	Microsemi	$8.857	$6.496	$8.86
N-Channel MOSFET	Infineon Technologies AG	$0.6538	$0.4094	$0.65
50 mΩ Resistors	TE Connectivity	$0.2652	$0.1538	$0.27
Total	-	-	-	$438.36

4.2 Labor

Based on the average salary for an Electrical Engineer ($68,000.00 USD/year) and Computer Engineer ($82,74.001 USD/year) [4] from the University of Illinois at Urbana-Champaign, the hourly wage is about $34.00 and $42.00, respectively. We estimate the hourly wage of each team member to be $39.00 and represent it as H. We estimate that we spent fifteen hours a week on this project for the entire semester, where W is the number of weeks. We account for some additional overhead by multiplying by a factor of 2.5. The equation is as follows, where L is the labor cost in USD.

$$L = 3 * H * W * 2.5 * 15 \tag{7}$$

$$L = 3 * \$39.00\ \mathrm{hr} * 16\mathrm{weeks} * 2.5 * \frac{15\mathrm{hr}}{\mathrm{week}} = \$70{,}200.00 \tag{8}$$

From source [16], we know that the average cost of a machinist in a machine shop is about $17.60 an hour. We will assume $20.00 for our calculations. When we spoke to the machine shop, they presented us with previous projects that they intended to recycle and adjust to our needs. We believe that the modifications took about 60 hours of work to complete. This adds $7500.00 to our grand total, assuming an overhead factor of 2.5.

4.3 Grand Total

The sum of the labor costs and parts cost sum to a grand total of $78,140.00.

5. Conclusion

5.1 Accomplishments

As noted in the introduction, there were three main functions that we intended to complete by the end of the course. We were able to accomplish all three of those requirements.

With the use of capacitive encoders, we limited our mount movement so that the solar panel would only ever face in the direction of the sun. From there, we programmed the microcontroller to allow 180 degrees of freedom along the horizon and 45 degrees of freedom for tilting. This then satisfied our first requirement.

With the use of four photoresistors and four small boxes, we were able to design and test a photosensing unit that could track a light source. The use of the boxes minimized and columnated the incident light, which in turn improved accuracy of light sensing and limited the region of incident light. An additional photoresistor was included to ensure zero ambient light, when all read low the mount would reset.

To size the battery, we performed many calculations to find the approximate energy consumption of our system. We then used that estimate to propose a battery size that rated for at least 30Ah, this recommendation also included energy consumption of the LED street light. We verified the battery met our projected energy consumption, and then theoretically verified that it could meet our actual consumption needs for a 48-hour period, see Appendix B, Table 4 for the Energy Consumption Table.

In addition to these successes, we collaborated with the machine shop to build a mount that could support our panel, could enable the use of the encoders, was weatherproof, and that didn’t buckle with wind gusts. We were also able to incorporate most of our circuit onto a PCB.

5.2 Uncertainties

We ran into issues with our Arduino unit and the encoders while integrating all the code. For our Arduino unit, three boards were damaged because of bootloader issues. There was an issue with uploading code to our ATMEGA chip after we removed the chip from the Arduino to place on a breadboard for testing. After we tested it on the breadboard, we were unable to put it back onto the Arduino unit to upload new code. We believe the problem was that the bootloader was not configured correctly. Our efforts to reupload the bootloader did not work. To fix this problem entirely, we could add circuitry to our Arduino board to program the chip directly on our board. This would eliminate plugging and unplugging the chip and will help with troubleshooting the project.

For the encoders, the encoder library we were using only worked with one encoder, while we needed it to operate with two. When we tried using the tilt motion encoders, they were not able to be configured. A possible problem is that Arduino has only two interrupt pins. Interrupt pins are vital for the reading of the encoders as they provide increased resolution.

5.3 Ethical Considerations

Our team acknowledges that there are safety concerns that go along with this product, should it be misused.

The battery is the most dangerous component of our project, and so requires additional considerations in order to ensure its safe operation, such as to prevent overcharging, shorting, and other damages to the battery. During our project build and testing of the battery, we were careful to mitigate the potential for danger by researching what would be the best battery for our project and to use appropriate connectors that included an inline fuse and a switch. A smart charger was also purchased to maximize the life of the battery, as well as to perform proper battery maintenance. The battery charge controller that we decided to include in our project also performs similar functions for daily charging. More on the standard operating procedure can be seen in Appendix C.

As our project is intended for outdoor use, we have made sure to use components that are specifically rated for outdoor use. This will ensure that none of the equipment shorts when it rains. We also intend to do further weatherproofing of the project.

These considerations are included in conjunction with the IEEE code of Ethics [5].

5.4 Future Work

There is still additional work that we feel is necessary to complete in order to have a fully functioning prototype.

The PCB design must be modified to ensure a fully integrated circuit. The work includes rerouting the traces to ensure that the motor driver is getting appropriate voltage values. It is also important to change the traces to the microcontroller, as it was heating up. These changes will allow the system to operate without the use of the breadboard and Arduino packaging. Beyond this, we also feel it is important to include microcontroller programming capabilities to the PCB. This will allow changes to be made directly on the PCB as opposed to having to transfer the chip to an Arduino to be reprogrammed.

The project is intended to be used outdoors, which requires full weatherproofing. In the building process, we made sure to take this into consideration, and made every attempt to fulfill this requirement as much as possible. This included weather proof connectors for the power system and covered motors. The next step to be done upon completion of the build is to fill holes to the base and photoresistor boxes with silicon or foam to prevent water build up. There should also be a clear wrap that covers the holes at the face of the sensing boxes. Finally, a container is necessary for the battery to ensure that it is not damaged by the elements or wildlife.

More testing is required to develop a complete control system. This includes tracking the sun through clouds or going to solar noon, the difference between cloud cover and night, unexpected reboot conditions, angular feedback through the other teams wi-fi connectivity, and more power efficient movements.

5.5 Acknowledgments

This project would not have been possible without the support and guidance of the students and faculty who worked with us.

We would like to thank Greg Bennett, Scott McDonald, and the rest of the machine shop for their assistance in developing our project. We would like to thank Kevin Colravy for his advice and the use of the power lab and testing equipment. We would like to thank Yuchen He for making herself available to us to ask for advice. Lastly, we would like to thank Professor Karl Reinhard for his constant support of our project.

It has been an honor and a privilege to work with so many amazing people on this project.

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Appendix A - Requirement and Verification Table

Table 3 System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
Solar Panel: 1. Will supply voltage between 14.5V and 20V in optimal conditions. 2. Provide a current between 5A and 5.5A in optimal conditions.	1. Take the panel out when there is good light and measure the voltage with a multimeter. 2. Take the panel out when there is good light and measure the current with a multimeter. (Or) Using Ohm's Law measure the voltage across a resistor and divide the voltage by the resistance to find current.	1. Y 2. Y
Battery Charge Controller: 1. Must be able to take an input ranging from 15V to 20V and convert it to a PWM voltage output of 12V to 15V. 2. Must be able to prevent reverse current from the battery to the solar panel.	1. Connect the solar panel ends to a DC source and provide 18V and 5A, connect the battery ports to an oscilloscope and record the output. Should see a PWM around 14.6V. 2. Connect a 12V source to the battery lead and ground. Measure the voltage across the solar panel lead and ground.	1. Y 2. Y
Lead Acid Battery: 1. Must provide a voltage between 7V and 13V. 2. Must provide enough energy to power the whole integrated project for 2 days	1. Connect the positive and negative ends to a multimeter and measure the voltage. 2. Connect the fully charged battery to a 1Ω load. Measure the voltage at 10-15 minute intervals. Once the voltage reaches 12V calculate the capacity.	1. Y 2. Y
Voltage Regulators: 1. Provides 12V +/- 5% from a maximum source of 15V.	1. Connect voltage regulator to DC power source and measure output voltage using oscilloscope, ensuring the output voltage stays	1. Y 2. Y

2. Can operate at currents between 0A - 2A.	within 5% of 12V as the input voltage changes. 2. Draw 2A from the output of voltage regulator. Measure using an oscilloscope.	
Over-Current Circuit: 1. Transfers input voltage to output voltage within +/- 5%. 2. Turns off output voltage when 2A are drawn by load.	1. Connect circuit to DC source and compare input voltage to the output voltage. 2. Monitor how output changes with different loads. When load current is 2A output goes to 0.	1. Y 2. Y
Microcontroller: 1. Be able to send signals out (motor drivers) depending on the processing of the input signals (reading from photosensors). 2. Output of the microcontroller is 5V	1. Program microcontroller using ATMEL Studio to send a single bit(0x01) into port B0 and then a zero(0x00) at intervals of 1 second. 2. Plug in AT-MEGA, LED and a single resistor onto the breadboard following the schematic shown in Figure 4- Appendix B. 3. Run the code on the microcontroller and ensure that the LED is working as per the desired effect . 1. Program microcontroller using ATMEL Studio to send a single bit(0x01) into port B0 and then a zero(0x00) at intervals of 1 second. 2. Attach the voltmeter to the circuitry and watch the voltage go up to 5V and down to 0V periodically.	1. Y 2. Y

Motor Driver: 1. The test voltage should vary between 6V and 15V. 2. Give an output of 12V and -12V because this is what is needed by the DC motors	1. Connect each of the 4 ports on the L293D chip to the 4 ports on the microcontroller. 2. At 1 second intervals, program microcontroller to activate one of the pins and deactivate the previous one. What should happen is that the first motor should go clockwise, then counterclockwise. Then the second motor should start, and the first one should stop. Then, the second motor should move clockwise, and then move counterclockwise. 1. Connect each of the 4 ports on the L293D chip to the 4 ports on the microcontroller. 2. At 1 second intervals, program microcontroller to activate one of the pins and deactivate the previous one. Then, the multimeter would move between -12 and 12 V each second if the test is right.	1. Y 2. Y
Motors: 1. Both motors must be able to move our solar panel and mount (~18 lbs) in both directions for an input voltage between 6V and 15V. 2. Current draw under 18lb load must be less than 5A. 3. Motors and mount hold solar panel in place. 4. Characterize voltages required to move various loads.	1. Motors can move the mount for the full range of motion in both directions for input voltages between 6V and 15. 2. Measure the current to the motors when the mount is moved along both axis with 6V input. 3. Position solar panel at extreme angles and verify that with no input voltage the mount remains still. Test under strong wind conditions.	1. Y 2. Y 3. Y 4. Y

	4. Load solar panel mount with 5, 10, 15, and 20 lbs. Measure the voltage required to move the load.	
Photoresistors: 1. Must be able to distinguish a reasonable difference between 0V and 5V.	1. Attach a simple circuit with a voltmeter, a photo sensor, and a variable source of light nearby. 2. As you change the degree of light, notice the difference in the reading in the voltmeter. 3. For our measurement purposes, change the photos sensor and repeat the experiment to see which one gives the largest range of voltage readings.	1. Y
Encoders: 1. Provide our system with feedback of the physical location of the mount with a resolution of 1 degree. 2. Provide our system with feedback of the physical location of the mount with an accuracy of +/- 5 degrees.	1. $\theta = (\frac{1}{2048}) * 360 = .175°$ 2. Move the solar panel mount and compare the encoder output using oscilloscope to the physical angle. Basic bench test using an Arduino. Verify output signals with oscilloscope if needed.	1. Y 2. Y

Appendix B - Schematics and Results

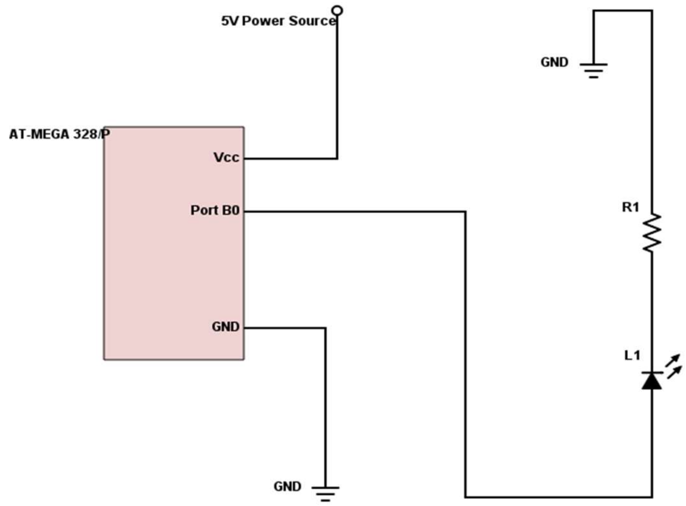

Figure 2: RV1 Microcontroller

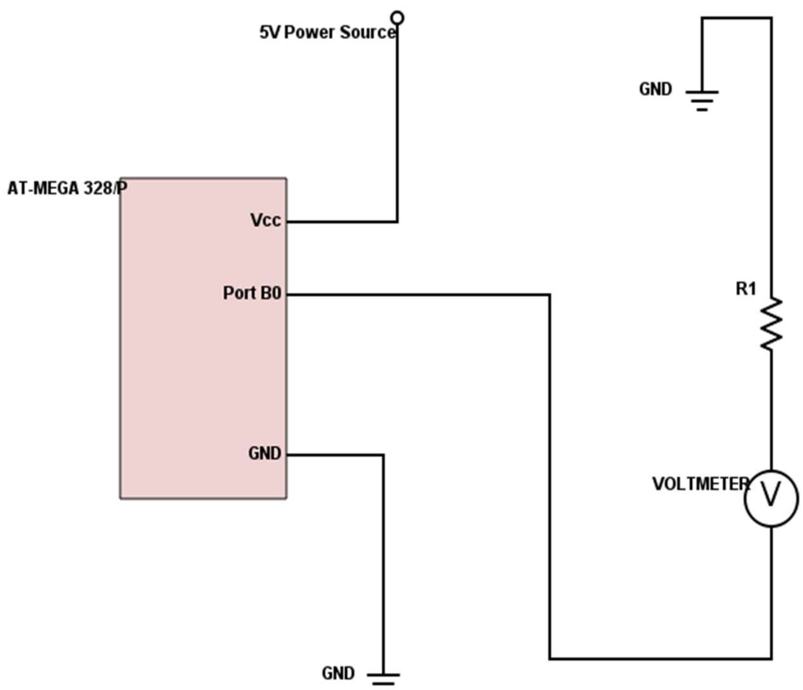

Figure 3: RV2 Microcontroller

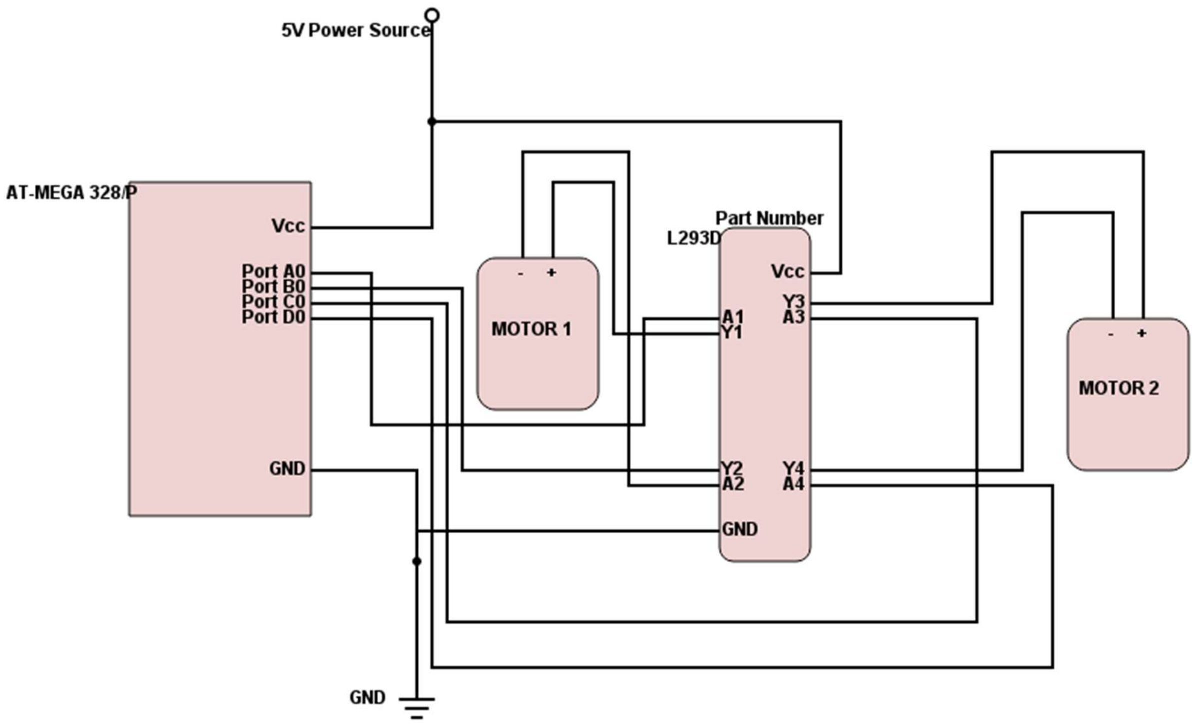

Figure 4: RV1 Motor Drive

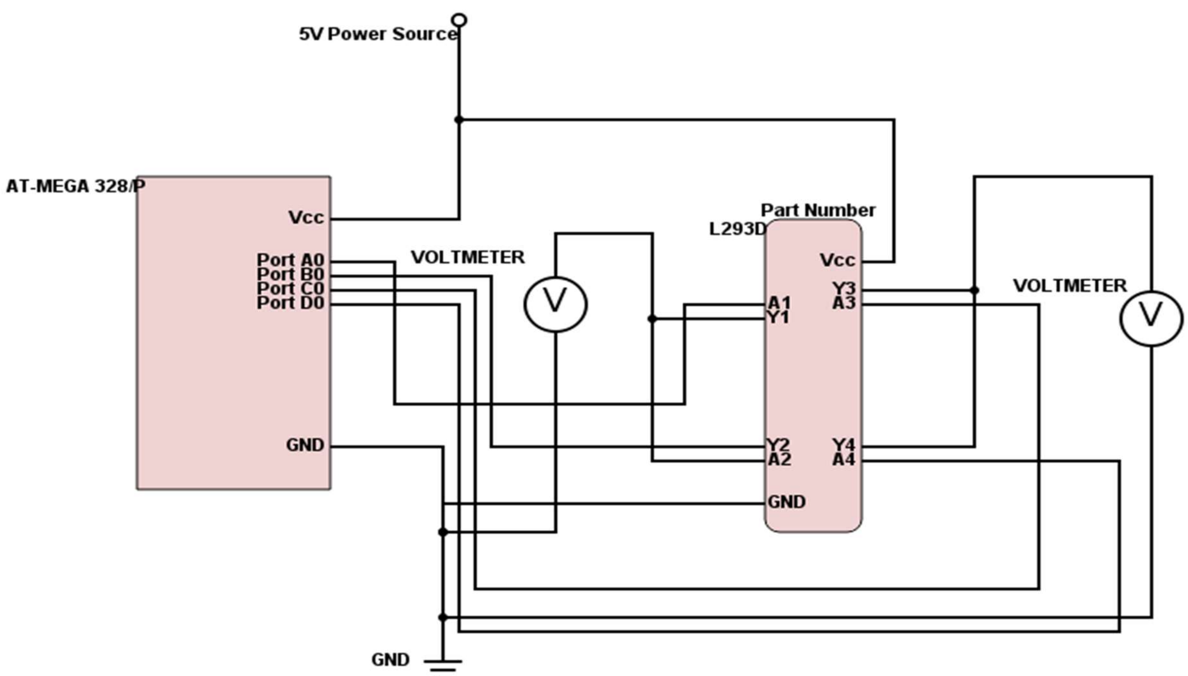

Figure 5: RV2 Motor Driver

Table 1. Function Table (Each Driver)(1)

INPUTS (2)		OUTPUT (Y)
A	EN	
H	H	H
L	H	L
X	L	Z

(1) H = high level, L = low level, X = irrelevant, Z = high impedance (off)
(2) In the thermal shutdown mode, the output is in the high-impedance state, regardless of the input levels.

Figure 6: Input Signal for Motor Drivers

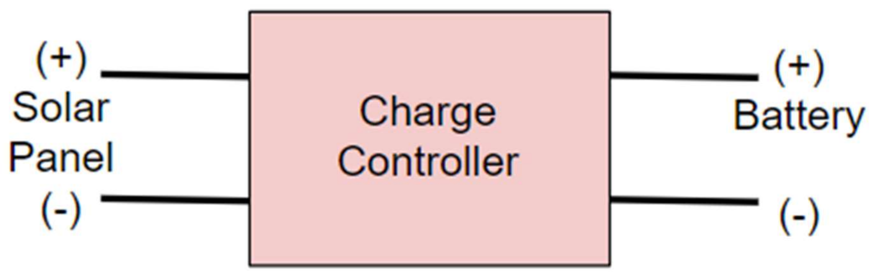

Figure 7: Schematic for the Solar Battery Charge Controller

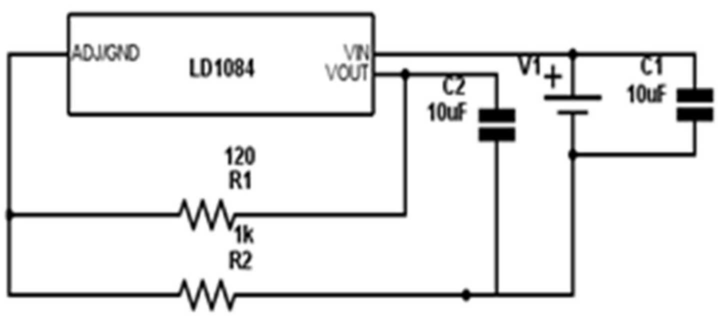

Figure 8: Schematic for the Voltage Regulators

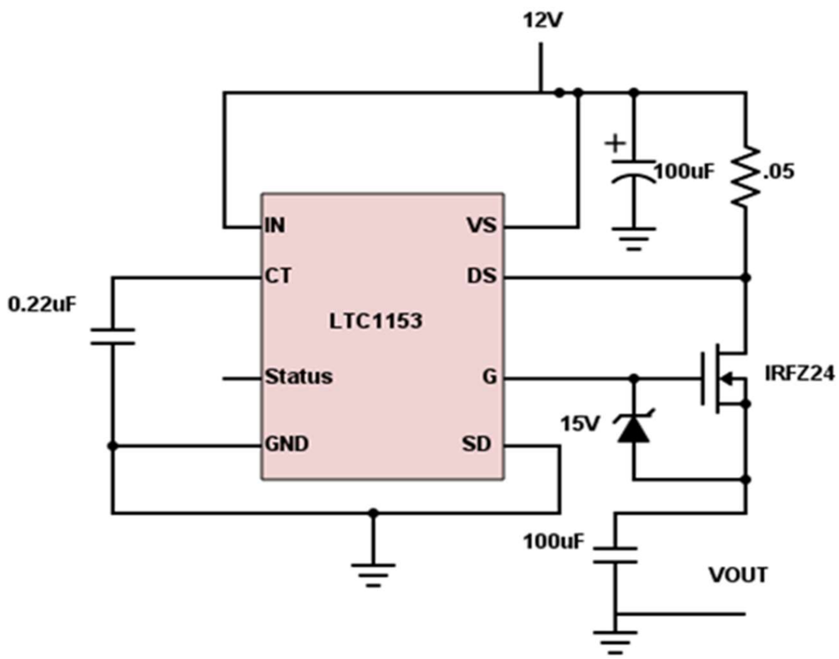

Figure 9: Schematic of Over-Current Circuit

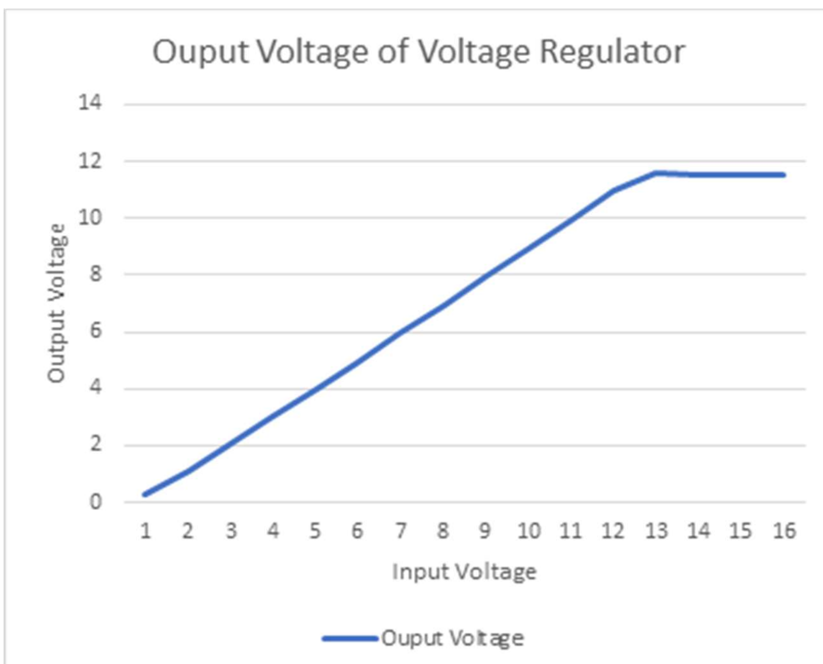

Figure 10: Output Voltage of 12V Voltage Regulator

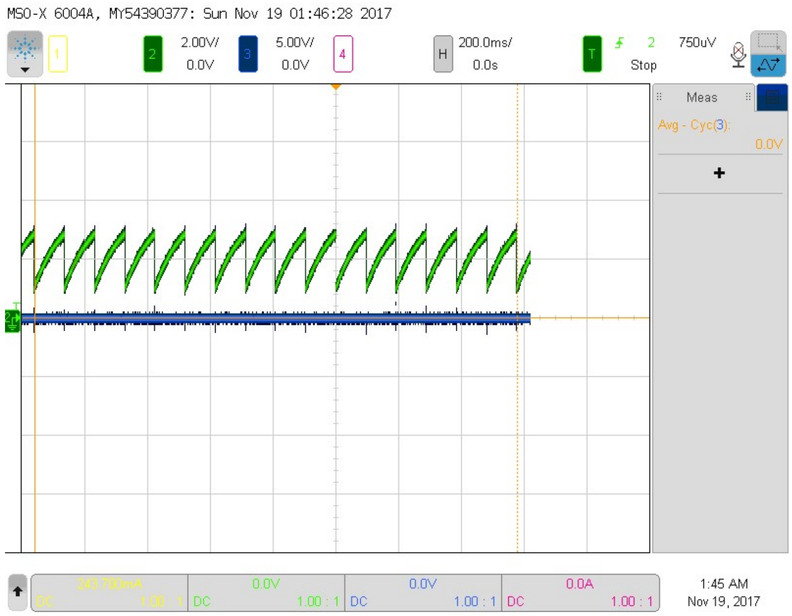

Figure 11: Output Voltage (Blue) and Timing Capacitor Voltage (Green) of Over-Current Circuit

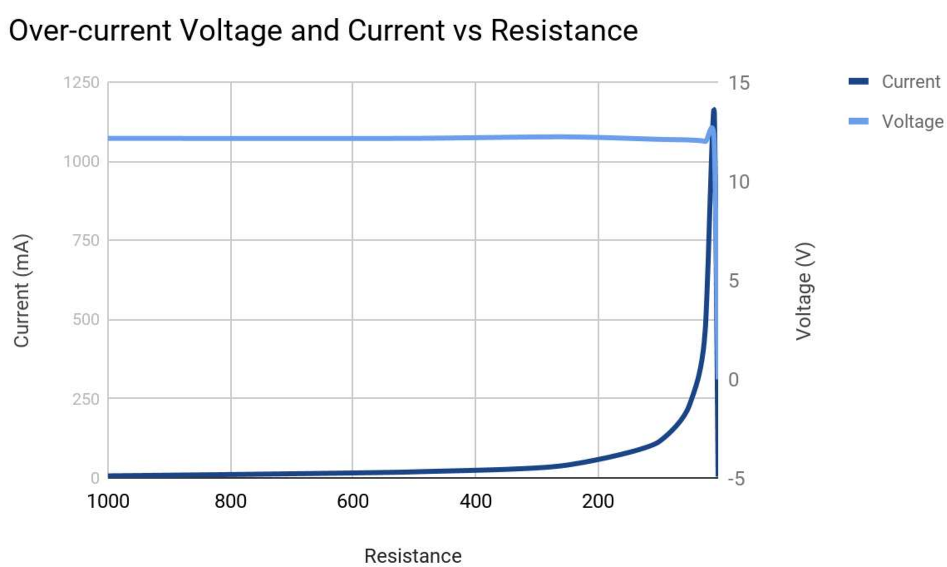

Figure 12: Over-Current Characteristics versus Resistance

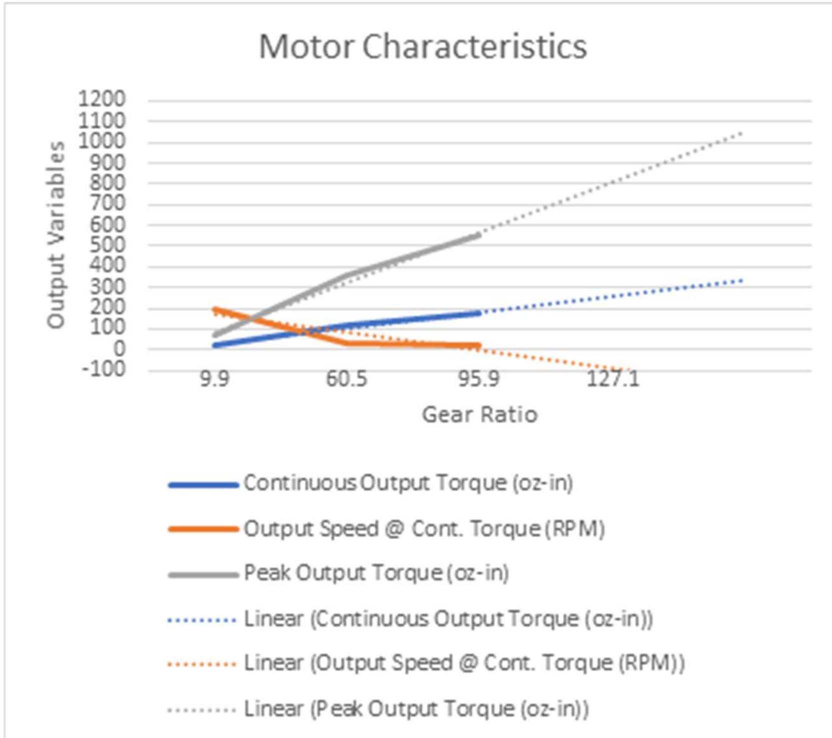

Figure 13: Estimation of Motor Characteristics

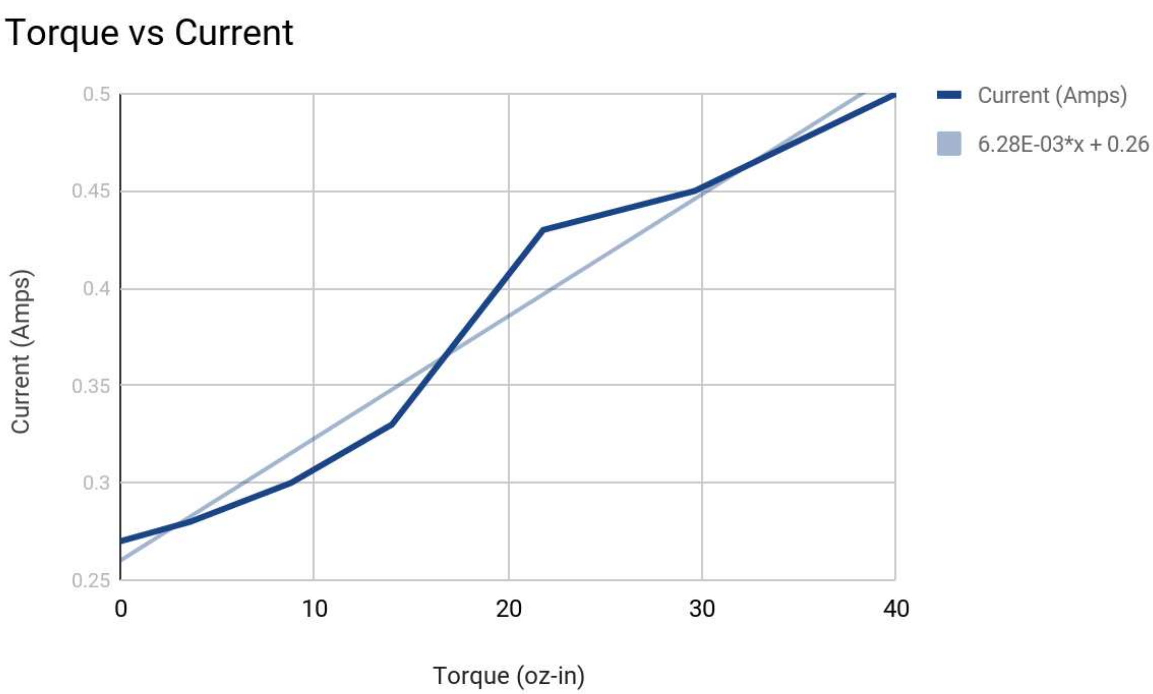

Figure 14: Torque vs Current of DC Motors

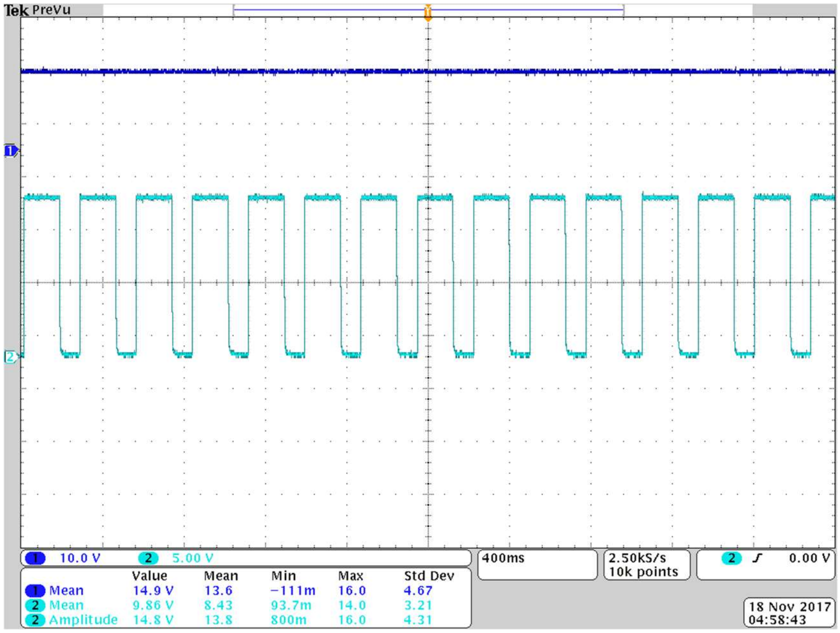

Figure 15: 15V Input to Solar Panel Terminals (Blue), PWM Output at Battery Terminals (Light Blue)

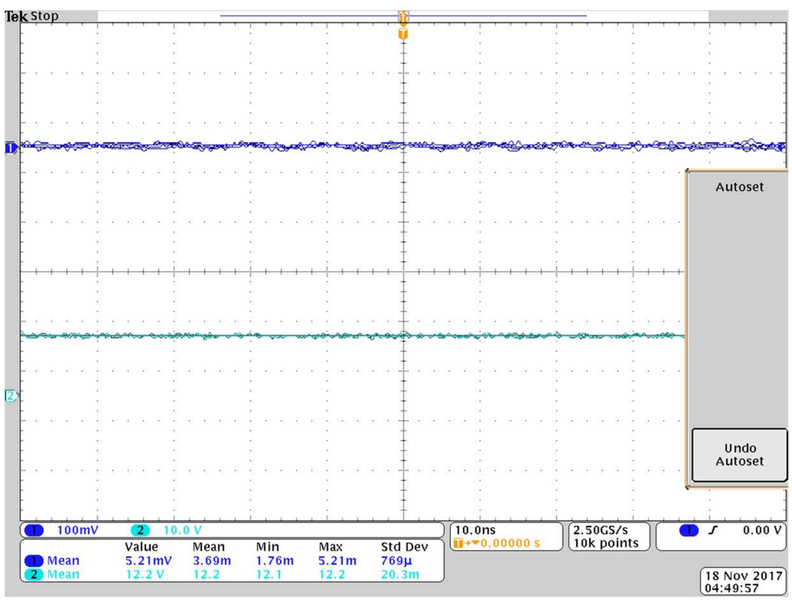

Figure 16: 0V Output at Solar Panel Terminals (Blue), 12V Input to Battery Terminals (Light Blue)

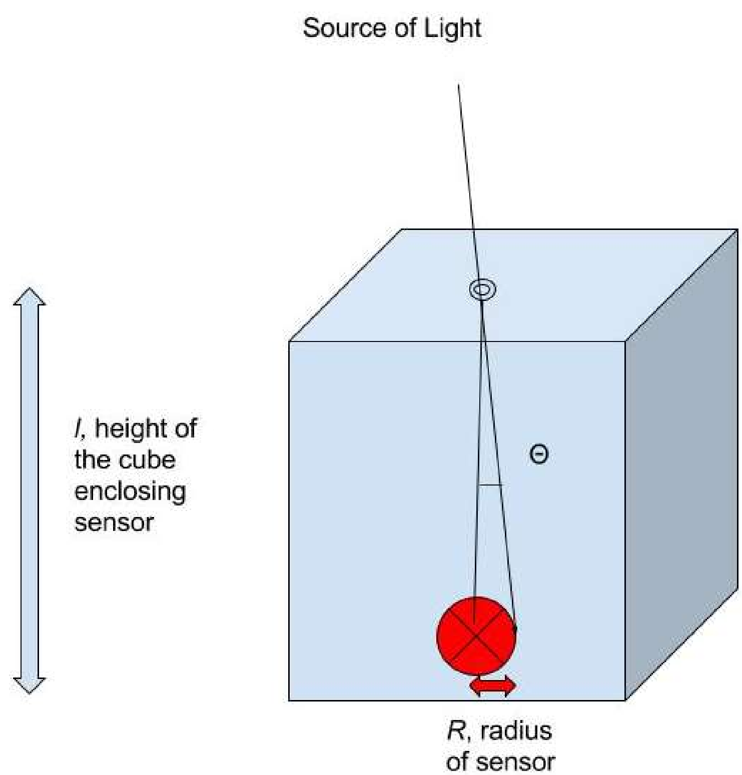

Figure 17: Transparent Diagram of Pin-Whole Photosensor Unit

Table 4 Energy Consumption Table

Load	Average Power [W]	Time/day [hours/day]	Average energy per day [Wh/day]	Capacity used per day [Ah/day]
Moving panel	13.44	.25	3.36	.28
Idle panel	.9204	23.75	21.86	1.82
LED Light	33	5	165	13.75
		Total	190.22	15.85

Table 5 Battery Capacity Test Results

Voltage (V)	Elapsed Time (mins)
12.646	0
12.48	10
12.39	20
12.27	30
12.18	40
12.12	50
12.02	60
11.99	65

Table 6 Encoder Angle Comparison

Physical Angle	Code Value	Calculated Angle
6°	26	4.57°
14°	69	12.12°
23°	120	21.09°
33°	178	31.29°
47°	254	44.65°
86°	474	83.32°

Appendix C - Lead-Acid Battery Standard Operating Procedure

Lead-Acid Battery

Standard Operating Procedure

Written By: Leonardo Larios

The purpose for this document is to set a standard operating procedure for testing lead-acid batteries for ECE 445: Senior Design. The focus of this document will be on safety features and precautions that should be considered and assimilated into future lead-acid battery testing.

While operating and testing a lead-acid battery it is important to have certain safety measures in place to mitigate the danger. One danger is the potential to short the battery whether it be by human connection or some equipment connection. In order to reduce this risk, consider requesting lab space in a lab that is designed to handle power equipment. The use of a separate lab should be considered because dedicated lab space reduces potential damage to the battery that may be caused in transporting. It also reduces the risk of untrained individuals interacting with the equipment.

Other considerations that should be taken include housing the battery within a battery box. using insulated wires, waterproof connectors, in line fuse protection, and in line switch (see Figure 18). These features mitigate the danger that comes when handling a live battery and live wire leads. The battery box eliminates the possibility of directly shorting the battery leads, as well as catching battery acid if the battery is damaged (Figure 19). The insulated wiring prevents direct contact with live wires. Waterproof connectors (Figure 20) should be considered for outdoor battery connections as water can pass current. The fuse will prevent current to flow, therefore eliminating power flow and risk for electric shock, if the current ever exceeds the fuse rating. Lastly, the in-line switch will allow for user current control as well as a visible indicator showing when the leads are active or not. This information will be useful for safe testing as well as giving a clear indication when not to short the leads. These precautionary actions should be taken seriously when preparing to test with a battery.

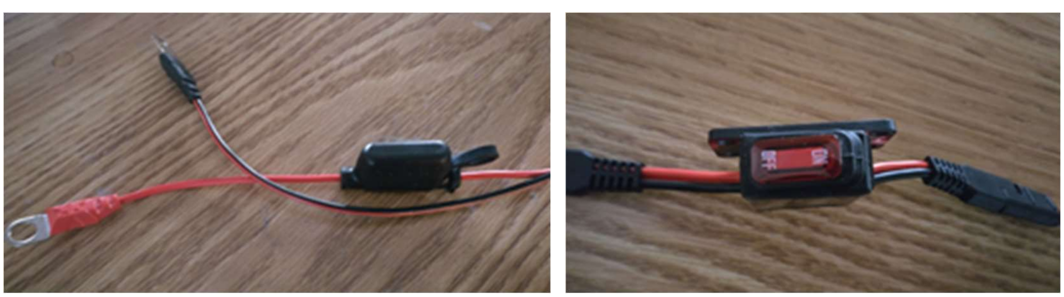

Figure 18: Left: In-Line fuse, Right: In-Line switch

Figure 19: Open and Closed battery box

Figure 20: Waterproof connectors

Considerations should also be taken on the chemistry of the battery. AGM and Gel type batteries are recommended because they do not use liquid acid to operate. As a result, battery acid leaks are not as common and these types of battery can also be mounted at an angle or upside down. Also consider the application of the battery. It is necessary to consider something like a deep discharge battery, that is designed to discharge to a lower capacity, and if this chemistry is better suited for the application.

Charging and maintenance of a battery are also crucial to maximizing the overall life as well as ensuring the health and ability. A smart charger (Figure 21) should be used to charge a battery. It will ensure that the battery is optimally charged depending on its current state of charge [21] as well as on its chemistry. There are many issues that can develop in a battery if it is not properly charged and maintained so this information is crucial to the longevity and save management of lead-acid batteries.

Figure 21: NOCO genius smart charger