# Sun-Tracking Solar-Powered LED Street Light

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**Abstract:** Street lighting is an essential utility especially in urban and industrialized areas because it provides illumination and safety for vehicles and pedestrians throughout the night. However, street lights are relatively inefficient; they consume large amounts of power from electrical grids and have predetermined operation times that are often non-optimal for the surrounding environment. The Sun-Tracking Solar-Powered LED Street Lamp is a self-sustaining device, built to replace the current lighting sources. The device features sun-tracking capabilities for maximum energy gathering and darkness recognition to establish optimal operation times. The project provides a reliable and enhanced alternative to current street lighting systems.

**Keywords:** Sun-Tracking Solar-Powered LED Street Lamp, energy gathering and darkness recognition

## I.INTRODUCTION

Energy exigency is the most important issue in today's world and one of the most Important building blocks in human development. Presently, the principal sources of energy. Available for our world are fossil fuels. These conventional energy resources are not only limited but also the prime culprit for environmental pollution. Considering the rate at which fossil fuels are consumed today, studies suggest that most of the known reserves of fossil fuels are likely to get exhausted by the end of this century (David and Ralph, 2009). To provide a sustainable and safer power generation to the future generation, there is a growing demand for renewable energy sources like wind, solar geothermal and ocean tidal wave. Renewable energy resources are getting priorities in the whole world to lessen the dependency on conventional resources. Solar energy is rapidly gaining the focus as an important means of expanding renewable energy uses (Fernando et al., 2011). Lots of researches have been carried out in improving solar cells efficiency which also involves the positioning of the cells to maximize energy extraction during the day using solar tracker (David and Ralph, 2009).A solar tracker is a device used for orienting a solar photovoltaic (PV) panel or lens towards the sun by using the solar or light sensors connected with the machine (example: stepper motor, servo motor, gas filled piston etc.) in order to maximize energy extraction during the day and increasing the photovoltaic cell efficiency against the conventional practice where solar panels are fixed mid-way between the geographical east and west with approximately 30 degrees towards the south. Mostefa 2013 revealed that this is not ideal position in maximizing energy extraction from the sun. It has been estimated that the yield from solar panels can be increased by 30 to 60 percent by utilizing a tracking system instead of a stationary array. A better way is to orient the panels continuously towards the sun, using single axis or double axes (Bill, 2008). Several factors must be considered when determining the use of trackers. Such factors includes; the amount of direct solar radiation, solar technology being used, expenses to install and maintain the trackers, and feed-in tariffs in the region where the system is deployed.

Concentrated applications like concentrated photovoltaic panels (CPV) or concentrated solar power (CSP) require a high degree of accuracy to ensure the sunlight is precisely directed at the focal point of the reflector or lens. Non-concentrating applications do not require tracking but using a tracker can improve the total power stored by the battery. Photovoltaic systems using high efficiency panels with trackers can be very effective (Rockwell, et al., 2011). The automatic solar tracking system is designed around two sub-systems. The first is the LDR for detecting the position where maximum energy could be extracted and the second is the solar panel with the control strategy. The aim of the LDR is to detect the maximum energy from the sun, and picks up the voltage induced. That voltage is compared with that sensed by the sensor mounted on the panels. If the panel voltage is less than that of the LDR voltage detection by a predetermined threshold offset, then the panels move and align themselves, otherwise they stay in their current position. A better way to orient the panels continuously towards the sun using a detecting mechanism (LDR) which detect the maximum energy from the sun is to align the panel with the direction of the sun.

## II. LITERATURE SURVEY

[1]Nell, R.D.; Kahn, M.T.E., "Measuring the light intensity of a hybrid powered CFL and LED lighting using 3D electronic vision in rotation of the solar panel, "*Domestic Use of Energy*

Nell's journal article discusses optimal usage of sunlight to power various light- producing loads. The article articulates the differences in application of lights that different locations utilize. The article especially highlights the interface of LED lights, a solar panel and battery like our project. Authors R.D. Nell represents the Department of Electrical Engineering in Cape Peninsula University of Technol, South Africa.

[2] E. Koutroulis and F. Blaabjerg "A New Technique for Tracking the Global Maximum Power Point of PV Arrays Operating Under Partial-Shading Conditions," IEEE, Journal of Photovoltaics. Vol. 2 Iss. 2. Piscataway, NJ. Feb. 7, 2012.

Koutroulis and Blaabjerg introduce solutions for partial shading upon photo voltaic. The journal article helps in understanding the operation that our sensors use. This information aids in program development for the sun-tracking system. Koutroulis works as a professor at the University of Crete and Blaabjerg works as a professor at Aalborg University. 26 other documents within IEEE cite this journal article.

Online Resources

[3]History Channel. Hoover Dam [Online]. Available: http://www.history.com/topics/hoover-dam

This website carefully documents the technical aspects of Hoover Dam including its power generation capabilities. The History channel published this article and contains many facts about Hoover Dam.

[4]Sun Lab. (1998, April). Solar Trough Systems [Online]. Available: http://www.nrel.gov/docs/legosti/fy98/22589.pdf

The Department of Energy produced the document and showcases the potential for solar energy producing power plants. These power plants can generate power comparable to fossil fuel plants while reducing CO2 emissions.

[5]C. Osborne. (2012, June 18). Street Lights: How Much Energy Is Actually Saved? [Online].Available: http://www.smartplanet.com/blog/smart-takes/led-street-lights-how-much- energy-is-actually-saved/

Article lists and explain the energy saving benefits of LED street lighting. LED use prove more effective than current solutions and has concrete evidence to support this claim.

[6]Gerdes, Justin. "Los Angeles Completes World's Largest LED Street Light Retrofit." *Forbes*.

Forbes Magazine, 13 July 2013. Web. 14 Nov. 2014.

<http://www.forbes.com/sites/justingerdes/2013/07/31/los-angeles-completes-worlds-largest-led- street-light-retrofit/>.

"Eartheasy." *LED Light Bulbs: Comparison Charts*. EarthEasy. Web. 14 Nov. 2014.

<http://eartheasy.com/live_led_bulbs_comparison.html>.

U.S. Patent

[7]J. Barrilleaux, "Selective light sensor and daylight management" U.S. Patent 8 860 316, June 20, 2013.

URL: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.htm l&r=25&f=G&l=50&co1=AND&d=PTXT&s1=photovoltaic&OS=photovoltaic&RS=photovolta ic

This patent contains information especially relevant to our solar-powered street lamp.

The description discusses using sensors to detect light and instructs how the circuit filters the signal and supports a light management module. This patent contains useful tips and suggestions applicable to this project. 31 other patents cite this patent and establishes its credibility. Inventor, Barrilleaux, owns 6 official U.S. patents all related to lighting systems and control.

Manufacturer's Datasheet

[8]Sunmodule, "Sunmodule off—grid Solar Panel," SW 50 poly RMA datasheet.

The datasheet provides vital information for solar panel voltage and current output and operation. This datasheet details the solar panel's size and weight characteristics, thermal characteristics, device materials, integration parameters and performance. This source comes straight from the manufacturer and the company boasts over 30 years of experience in off-grid solar applications.

Texas Instruments, "MSP430F15x, MSP430F16x, MSP430F161x

MIXED SIGNAL MICROCONTROLLER," MSP430 datasheet, Oct. 2002 [Revised Mar. 2011].

Books

[9] C.L. Mantell, *Batteries and Energy Systems,* 2nd ed. USA: McGraw-Hill, 1983

This source provides battery usage and storage techniques to aid in the energy harvesting component of my senior project. Cited 53 times, the well-written book includes several cited data tables explaining battery life, battery applications, size and construction

[10] P. Sorcar, "Lighting and Energy Conservation Standards," in *Energy Saving Lighting Systems, New York: VNR Co., 1982.*

This book provides energy conservation standards and exterior lighting calculations able to improve lamp and illumination efficiency. Cited by 15 authors as recent as 2009 by the Architectural Science Review. Author, Sorcar, holds the CEO and president positions of his lighting company Sorcar Engineering Inc.

[11] J. Lindsey, "Floodlighting, Parking Lots, and Street Lighting," in *Applied Illumination Engineering,* 2nd ed. Lilburn: Fairmont Press, 1997, ch. 14, pp. 363-393.

This book provides calculation methods for lighting, discusses light loss factors, and calculations for watts per square foot. It also discusses types of lamps and appropriate usage. Cited by 52 authors, the well-written book displays complete diagrams and data. Lindsey has experience at Southern California Edison, served on the California Energy Commission's Professional Advisory Group and served as a charter member for the Lighting Efficiency Advisory Group.

[12] L. Castaner and S. Silvestre, *Modelling Photovoltaic Systems using PSpice,* West Sussex, England: John Wiley & Sons Ltd., 2002.

This book helps in computer testing of solar panel systems using Pspice. It discusses photovoltaic electrical characteristics and technical practice of solar cell arrays as well as battery modelling. 343 authors cite this source for its thorough procedures in Pspice modelling.

[13] T. Markvart et al, *Solar Electricity*, West Sussex, England: John Wiley & Sons Ltd., 1998.

The book provides complete information about solar radiation to engineering to applications. This book serves to explain solar cell function, electrification using solar cells and calculating voltage and battery operation. Author, Tom Markvart, obtained his BSc and PhD in Mathematical Physics from the University of Birmingham, Southampton and awarded the Royal Academy of Engineering/EPSRC Clean Technology Fellowship as Head of Solar Energy Centre in 1994. 16 other collaborators from Spain Netherlands, Ireland, Germany, Italy and U.K. contributed to the book.

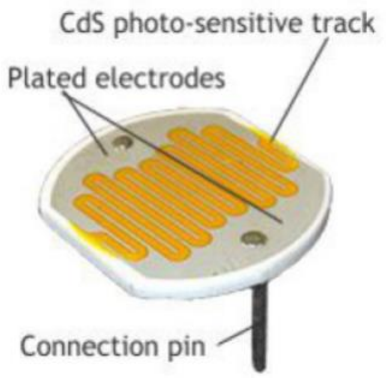
[14] D. Munro et al, *Photovoltaics in the Urban Environment: Lessons Learnt from Large-Scale Projects*, Sterling, USA: Earthscan, 1990.

The book gives case studies of implemented photovoltaics in areas spanning Europe and Northern Asia indicating system concept, costs, integration, design, and monitoring. This resource aids our senior design proceedings. The book completely explains the successes and drawbacks of the various projects.

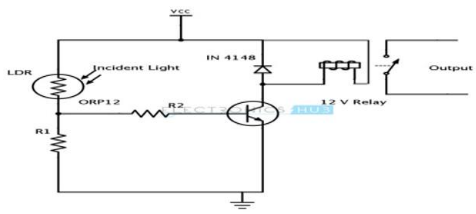
## III. DESCRIPTION OF THE PROJECT

Solar trackers are rising in popularity, but not everyone understands the complete benefits and potential drawbacks of this system. It is a fantastic system for energy output. Solar panel tracking solutions are a more advanced technology for mounting photovoltaic panels, unlike stationary mounts, which hold, panels in a fixed position, can have their productivity compromised when the sun passes to a less-than-optimal angle. In other to overcome this, solar trackers automatically move to "track" the progress of the sun across the sky,

thereby maximizing output. The unique feature of this system is that instead of taking the earth as its reference, it takes. The sun as a guiding source. Its active sensors (LDRs) constantly monitor the sunlight and align the panel towards the direction where the sun intensity is at maximum. Should the sun get invisible e.g. in cloudy weather, then without tracking the sun the ASTS keeps rotating the solar panel in opposite direction to the rotation of earth. But its speed of rotation is same as that of earth's rotation. Due to this property when after some time e.g. half an hour when the sun again gets visible, the solar panel is exactly in front of sun.




Physical representation of an LDR sections.




## OPERATIONAL SEQUENCE

The circuit consists of the following stages for the proper operation. The circuit uses two LDRs subjected to the same illumination. The half the operating voltage is then applied to the non-inverting input terminal (positive terminal) of the battery and to the inverting input terminal of battery. The sensor stage comprises of the two LDRs, when the position of the sun changes, the illumination affecting LDRs, R1 and R2 is different, provide if they are at an angle to each other. In this case, the illuminated LDRs will provide information to the DC motor (Jack Drive) which gives the output by comparing the initial half supply voltage to the input voltage from the illumination light falling on the LDRs thereby resulting into clockwise and anticlockwise rotation of the solar panel along its axis. The driver stage comprises of the two transistors is connected in a bridge for reversing of the motor. The transistor T1 provides clockwise rotation of the motor, why the transistor T2 provides anticlockwise rotation of the motor.

The protecting devices are the Diodes to which functions are to save the motor by suppressing the effect of the voltage peak of the motor when switched on. The presetting stages comprise of the three variables resistor, and . Two of which are adjusted so that the motor is idle when the LDRs are subjected to the same illumination while the third is for the adjustment of the solar lamp. If more light reaches R1 and R2, voltage at point A rises to more than half the supply voltage. The result is that the comparing output of A1 goes high and transistor conducts. The motor then runs a clockwise direction. If the illumination of the LDRs changes so that the voltage at point A drops to less than half the supply voltage, output of A2 goes high and transistor conduct, motor then rotates in an anticlockwise direction.

## REQUIREMENTS AND SPECIFICATIONS

The Solar LED Street Lamp improves many features of existing lighting systems. Table 1 shows the project's marketing requirements and product specifications. These requirements include basic marketing strategy and maintain appropriate safety standards. The project's requirements ensure safe design, improve device utility and decrease harmful environmental impact. An overview of the engineering specifications includes component operation ratings, device size and total ideal product cost.

Table 1 Solar LED Street Light Requirements and Specifications

| Marketing Requirements | Engineering Specifications | Justification |
|---|---|---|
| 1, 4 | Device operates on one battery < 24V | Battery recharges and operates continually; energy storage occurs during day and used at night |
| 2,4 | Solar panels rotate ≥ 90 degrees | Solar panels moves to face a direction to receive most optimal sunlight |
| 3,5 | Light sensor detects ambient brightness between 10 and 1000 lux | Illumination adjusts from minimum in sparse sunlight to maximum light at darkest night |
| 4,7 | Solar cell does not exceed 5ft by 2 ft | Supply power comes from solar panel to operate movement control and light. The design generates enough power for self-. Sustainment |
| 7 | Completed device does not exceed 5 ft x 3ft x 2 ft | Minimal space usage reduces systems environmental impact |
| 5 | System withstands 40 mph wind speeds and 70% humidity | Design endures harsh weather conditions for minimal repair services |
| 6 | System produces > 10 lux | Safe street lighting design requires at least 10 lux for full pedestrian lighting on sidewalks [19] |

Table 2 Continued Specifications and Requirements Table

| Marketing Requirements | Engineering Specifications | Justification |
|---|---|---|
| 8 | Device cost does not exceed $600 | Project anticipates maintaining a low cost product |
| 9 | Overcurrent device prevents extensive system damage | Bureau of Street Lighting standards mandate a control component for all streetlamps. |
| 10 | System operates at a height > 25 ft | Los Angeles Department of Public Works specifies a legal streetlamp height requirement |

**Marketing Requirements**

1. Rechargeable System
2. Sun-tracking capable System
3. Solar Powered
4. Durable, weather-resistant design
5. Bright light
6. Compact design
7. Inexpensive system
8. Device adheres to county approved safety standards.
9. System reduces susceptibility to vandalism

## IV. DESIGN

### SIMPLE CHARGE CONTROLLER CIRCUIT

The major components were interfaced first to establish the component's working functions. The charge controller uses a small amount of voltage to operate and regulate charging from the solar panel. When the solar panel is connected, the charging cycle is initiated by a series of battery indicator lights and a green light for solar panel charging. If the charge controller measures that the battery retains optimum voltage, the battery is connected directly to the output terminals of the charge controller

### LINEAR ACTUATOR

During individual component testing, we found that a moderate and preferable speed of the linear actuator needed to rotate the solar panel at a comfortable rate was achieved when the actuator was supplied 17 volts. We designed this voltage requirement by a resistive divider using two 8-ohm amplifier resistors. The actuator draws a current of approximately 0.6 amps when 24 volts are applied. The amplifier resistors have low resistance but can handle of power.

### H-Bridge Circuit

Next, we designed a system capable of switching the voltage polarity supplied to the actuator. We accomplished voltage switching with an h-bridge design. Figure 3, a LT Spice model was created where four mosfets make the h-bridge. Two NPN transistors control the gate voltage supplied to each branch of mosfets. Our design prevents short circuit because no two series mosfets will be activated due to the way the bjt chips are implemented.

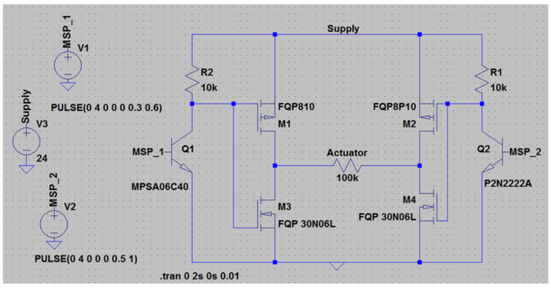



Fig.1 LT Spice schematic of H-bridge circuit to Power Linear Actuator

Figure shows a plot of square wave signals sent to the base terminal of each npn bjt. The signals are 5-volt square wave pulses and emulate the signals supplied by the MSP430. The signals are purposely staggered to account for all four possible combinations of on and off for two signals.

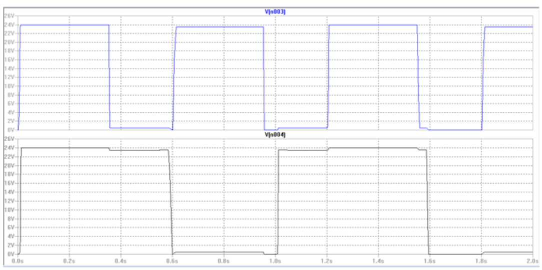


Fig.2 Control Voltage Signal Waveform Plot

Figure shows the node voltages at the load terminals of the H-bridge used by the linear actuator. When a npn base terminal sees a high, it forward biases the npn and allows current to flow. The terminal sources current through the resistor and connects both mosfet gates to ground. This turns on the pmos and turns off the nmos, making the load terminal high. When the bjt sees a low signal, the base emitter junction is reverse biased and no current flows. The collector terminal therefore sees the battery voltage, the PMOS is turned off and the NMOS is turned on. The load terminal is then connected to ground.

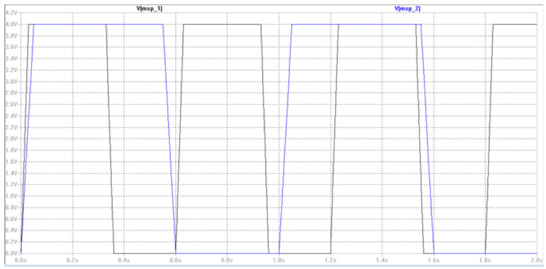


Fig.3 Figure Voltage Signals Waveforms Measured at both Nodes of the Load Terminals of the H-bridge

Figure 6 shows the voltage waveform seen across the load terminals of the h-bridge. The plot simulated shows that the load is capable of seeing both +24- and -24-volt supply voltages. This circuit is appropriate for us to use to drive our linear actuator component.

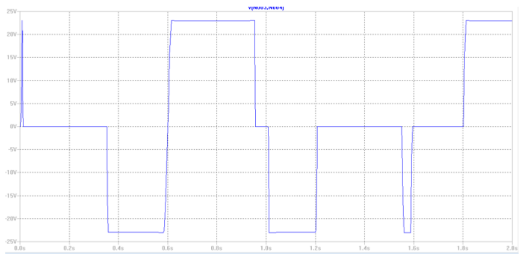


Fig.4 Figure Simulated Output Voltage Waveform of the H-bridge

### FUNCTIONAL DECOMPOSITION LEVEL 1 BLOCK DIAGRAM

The level 1 block diagram **below** shows the system sub-module configuration and interaction. This level includes the following components: a solar panel [11], a 12 V battery, an ambient light sensor [10], comparator, MSP420 Microcontroller [12], Motor, Pulse Width Modulator and LED Light Network. The diagram illustrates the relationship between power supply and microcontroller signal flow. The solar panel and battery power all other components. The light sensor and comparator handle light timing operation and LED light brightness. Table 4 through. outline the Level 1 block diagram modules and explain the module's inputs, outputs and functionality.

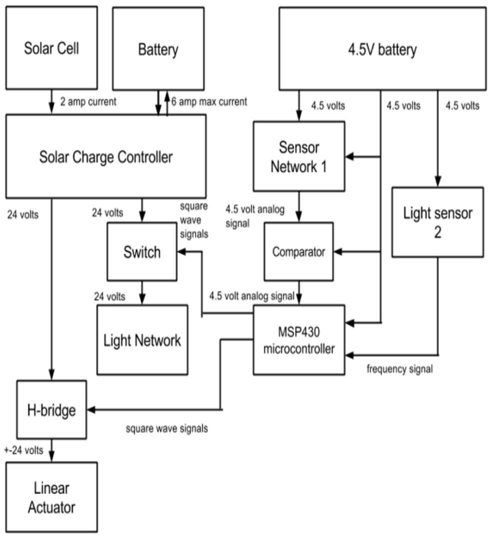



Fig.5 Solar LED Street Light Level 1 Diagram

## RESULTS

Integration of the system involves combining the base, solar panel pole, and electrical components. The fully integrated system with all the components is shown in Fig.6 below.

Figure.6 Photo of Fully Constructed close up photo internal components of base housing

For the linear actuator, we attached power resistors to the leads to observe the change in current when the actuator drives move the load. Using a multimeter, we measured about 0.38 A when the actuator's arm was not fully extended to about 0.46 A when the actuator's arm fully extended. Without the power resistors, the current varied between 0.64 and 0.71 amps. More current through the actuator increased the speed of the arm extension and used more charge from the battery. We added power resistors to the circuit to limit the current through the actuator. As a result, the arm moved slower while taking less charge from the batteries.

The LED light bulb represents the electrical load of the system. The LED light bulb regulates itself so it will always draw 10 Watts of power. Theoretically, during nightfall, the LED light bulb turns on and illuminates for 9 hours. However, our experimental results showed that the LED light bulb only stays on for about 2 hrs. The charge controller prevents total discharge of the battery by protecting the battery voltage. Total battery discharge would damage the battery cells and diminish charge capacity. At around 23V, the charge controller opens an internal switch to prevent current leaving the battery. To solve this issue, we would need to buy a battery with a bigger amp-hour capacity because current leaving the battery lowers the battery voltage. A bigger Ah capacity would allow the system to safely discharge current to the light bulb.

Moreover, the three light sensor network has some drawbacks. The TEMP6000 reads the light as an input and outputs a voltage. A high output voltage indicates the sensor reads a high lumen input. A lower output voltage would indicate darkness; however, this sensor cannot read low lumen brightness. The sensors are unable to measure the darkness threshold desired to turn on or off the light. The resulting threshold level corresponds to a brightness that was less than ideal for the operation of the system.

Lastly, the H-bridge used to drive our linear actuator could use better components. When we first tested the H-bridge, the actuator extended and retracted its arm to move the solar panel. After some trials, a single NMOS transistor chip caught fire but the rest of the circuit remained safe. After implementing and testing the h-bridge using the batteries with second set of NMOS chips, we found they failed a second time. We observed that the NMOS' gate-source voltage rating cannot handle the battery voltage across its terminals. Future projects reserve the obligation of changing the design of the h-bridge circuit.

**Solar output of PV panel in fixed mode**

| Time of the day | Voltage(V) | Current (A) | Power (W) |
|---|---|---|---|
| 9 | 13.87 | 0.88 | 12.21 |
| 10 | 15.29 | 0.97 | 14.83 |
| 11 | 15.09 | 0.95 | 14.34 |
| 12 | 16.17 | 1.07 | 16.33 |
| 13 | 18.08 | 1.17 | 21.15 |
| 14 | 16.25 | 1.06 | 17.23 |
| 15 | 15.88 | 0.99 | 15.72 |

**Solar output of PV panel in tracking mode**

| Time of the day | Voltage(V) | Current (A) | Power (W) |
|---|---|---|---|
| 9 | 16.04 | 0.95 | 15.24 |
| 10 | 16.48 | 1.02 | 16.81 |
| 11 | 16.4 | 0.98 | 16.07 |
| 12 | 16.75 | 1.09 | 18.26 |
| 13 | 18.09 | 1.17 | 21.16 |
| 14 | 17.3 | 1.13 | 19.55 |
| 15 | 16.83 | 1.11 | 18.68 |

## CONCLUSION

The project experienced successful progress. Our team built and tested a working module that accomplished the essential goals of the project. Our final hardware construction easily tracks the sun within a 138-degree sweep and exhibits self-sufficient capability by taking in solar energy and activating the LED light bulb at a certain brightness threshold. If commercially built, this system could be used as an off-grid system to provide street lighting for hard-to-reach communities such as rural areas. The project, as stated before, is a prototype structure that would not be directly implemented in actual applications. The allocation of hardware tasks remains the same in a more practical construction. Hopefully, this project inspires others to think about sustainable and alternative methods of generating electricity.

### Future Considerations

This section lists the possible improvements that the system could have used. If someone were interested in continuing this project, they would implement these changes.

First, the system could have used a better battery capacity. As of now, the light bulb only stays on for two hours because the charge controller prevents total discharge of the battery. A bigger amp-hour capacity would allow the battery to discharge more current to the light bulb without disturbing the charge controller.

Secondly, the system could have used a 2-axis sun tracking motion. A gearbox or servo motor may move the pole in a circular motion. This would give the system a 360 degree sweep in the x-axis. Next, a linear actuator would be used to control the y-axis movement. For y-axis tracking to work, the solar panel mounted pole must be retrofitted with an adjustable joint corner.

Lastly, this project could benefit from a dimmable light bulb. The dimmable light bulb because the microcontroller would control the lumens output. In order to accomplish this feature, we need to incorporate a more sensitive light sensor to the project. Our current light sensors are unable to detect the huge differences in darkness. After a certain lumen threshold, the light sensors output the same voltage. A more sensitive light sensor would allow us to input logic into the microcontroller to correctly output the optimal lumens for the current atmosphere.

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