Sun-Tracking Solar-Powered LED Street Light

A Senior Project

Presented to

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In Partial Fulfillment

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Bachelor of Science

by

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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.

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CHAPTER 1 INTRODUCTION

Renewable energy usage has steadily increased through the years because the world has a finite amount of fossil fuels. Unlike finite fossil fuels, virtually limitless amounts of energy come in the form of solar, wind, hydro, and other energies. These energy sources emit clean byproducts and do not damage the environment with CO2 emission and fossil fuel pollution. Renewable energy resources must be used to decrease the negative impact of fossil fuel waste.

Figure 1 below, from the U.S. Energy Information Administration, illustrates the huge usage of fossil fuels in millions of kilowatt-hours generated in the United States alone [22].

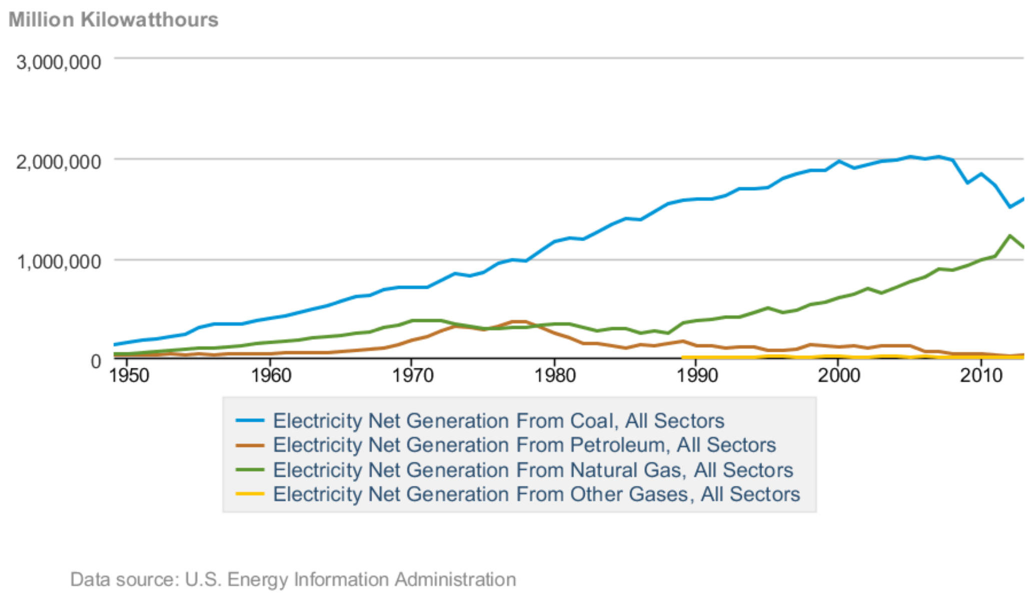

Figure 1 Fossil Fuel Emissions in Millions of Kilowatthours provided by the U.S. Energy Information Administration

Figure 2, also from the U.S. Energy Information Administration, shows the small rise in renewable energy usage by the United States. Both Figure 1 and Figure 2 show the reliance of the U.S. on fossil fuel and the underdevelopment of energy generation from renewable sources.

Coal and petroleum produce one thousand times more kilowatt hours than wind generation, the most utilized renewable energy. To reduce its carbon footprint, the U.S. needs to consider advancing more ecologically friendly utilities.

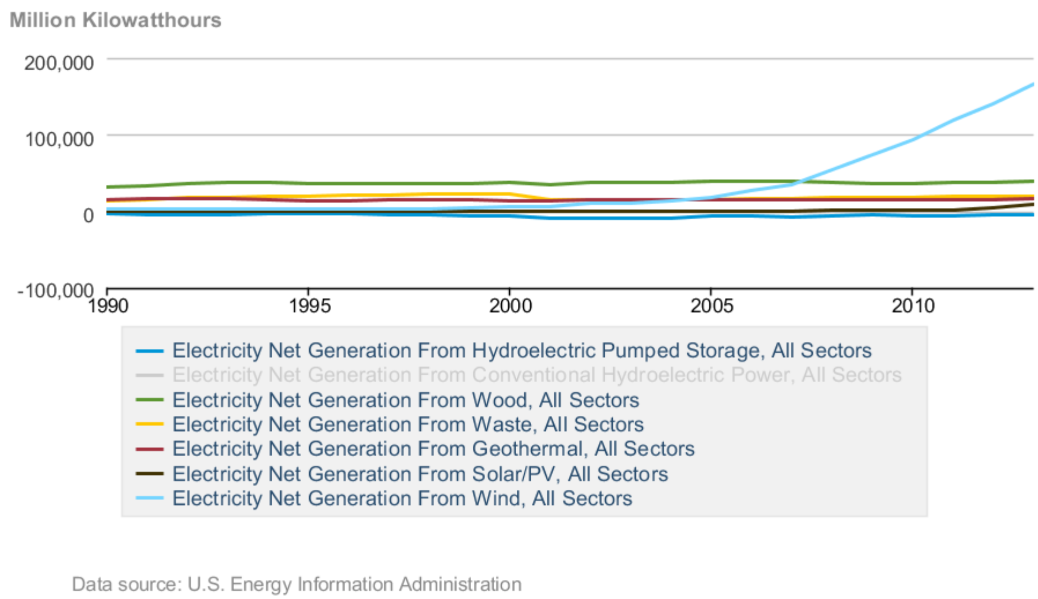

Figure 2 Renewable Energy Electricity Generation in kilowatthours according to the U.S. Energy Information Administration

One of the most common electrical utilities in the world is street light. Street lights exist everywhere in the world because they provide illumination during dark hours. Most current streetlights seem primitive because they only have an on and off mode, have a single intensity and have the same controller source. On a national level, the United States spends about 163 billion dollars a year on residential outdoor lighting [21]. Our project, the Solar LED Street Light, changes this statistic because its operation relies solely on solar energy.

Our project, the Solar LED Street Lamp reduces electrical grid energy consumption and serves as an example to advocate for renewable energy. The Street Lamp addresses the concern for clean energy while improving the efficiency of existing systems.

Our device uses LED lighting because of their low wattage ratings compared to previous lighting sources. Our chosen light source is powered by 25 watts of power. Current sodium-based light bulbs consume between 138 to 144 watts over a 13 day period where as LED lighting consumes between 41 to 69 watts over the same period. These base values applied over a year represent savings of 50 to 70 percent or 280 to 400 kWh per year [20]. LED lights last longer and shine brighter light than traditional light bulbs. Good economic practice recommends switching to LED lighting since LED lights consume less power [9]. The self-sustaining Solar LED Street Light does not need to rely on power from the power grid.

CHAPTER 2 Planning

2.1 Customer Needs Assessment

The design requirements for the Solar LED Street Lamp include the following:

- The product does not impede a customer's lifestyle
- The lamp provides light when needed at any time of the day
- The LED brightness depends on the amount of ambient atmospheric light
- The finished product resists harsh wind and humidity environments
- The product's self-sufficient solar-powered battery reduces power supplied by the city.
- The product design abides by California city standard safety electrical codes [19].
- The product operates in accordance with its geographic location's average ambient atmospheric light conditions

These requirements outline the project's design and implementation standards.

2.2 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 system's 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]
5	System operates between 20°F to 140°F	Marketing targets western states that experience hotter average temperatures

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 street lamps [19]
10	System operates at a height > 25 ft	Los Angeles Department of Public Works specifies a legal street lamp 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

Error! Reference source not found. outlines the deliverable due dates for major milestones of the project. These checkpoints serve as progress marks in the production process. The enumerated events take place in 2015.

CHAPTER 3 Design

3.1 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.

3.2 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 ___ watts of power.

3.3 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.

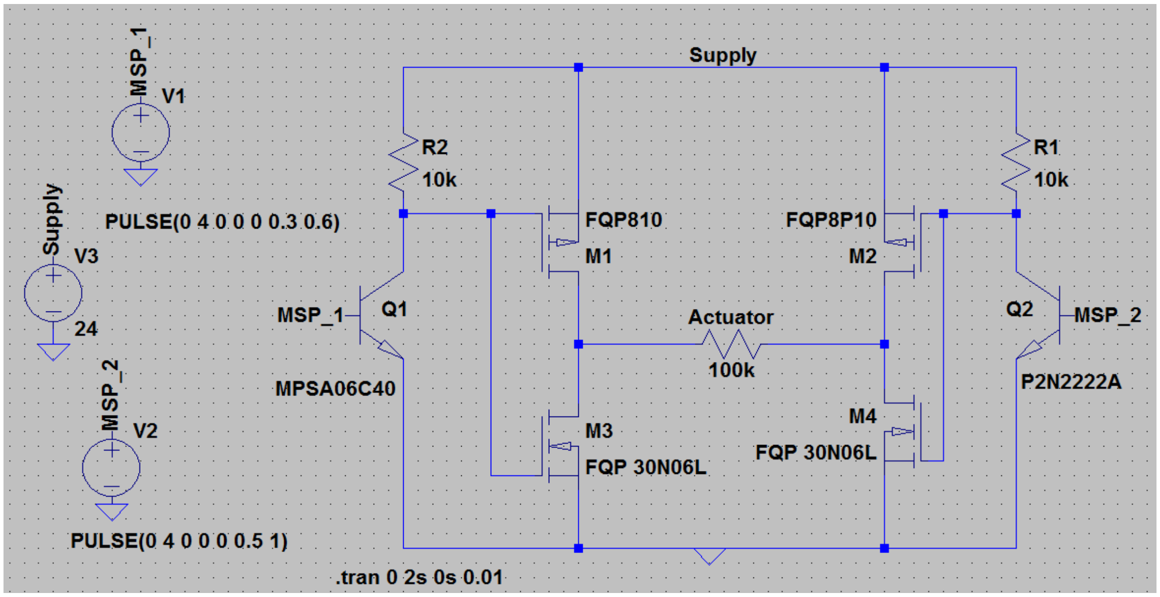

Figure 3 LTSpice schematic of H-bridge circuit to Power Linear Actuator

Figure 4 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.

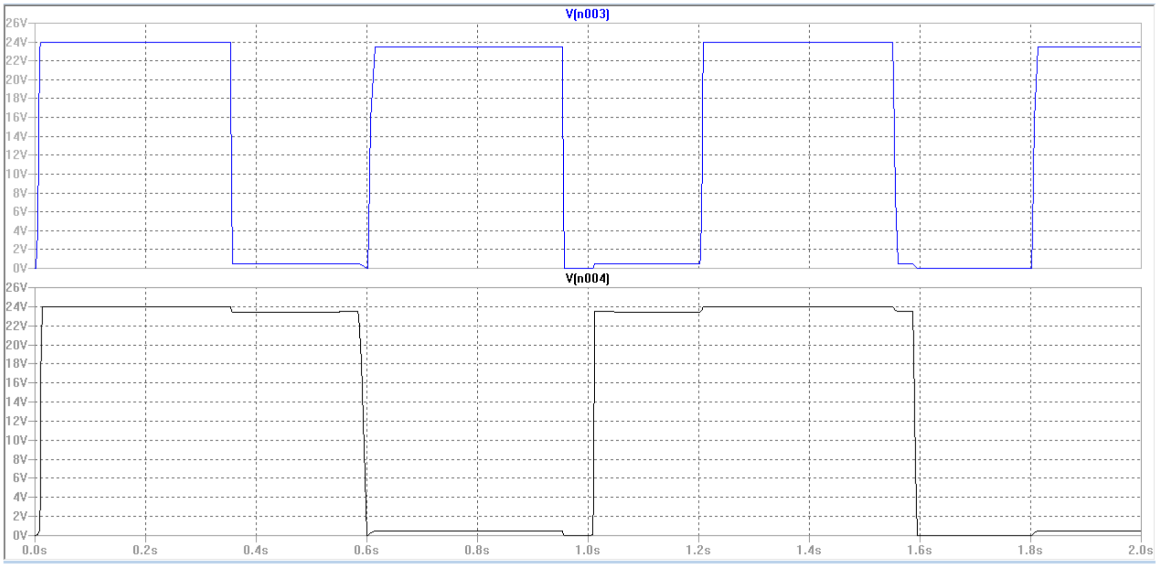

Figure 4 Control Voltage Signal Waveform Plot

Figure 5 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.

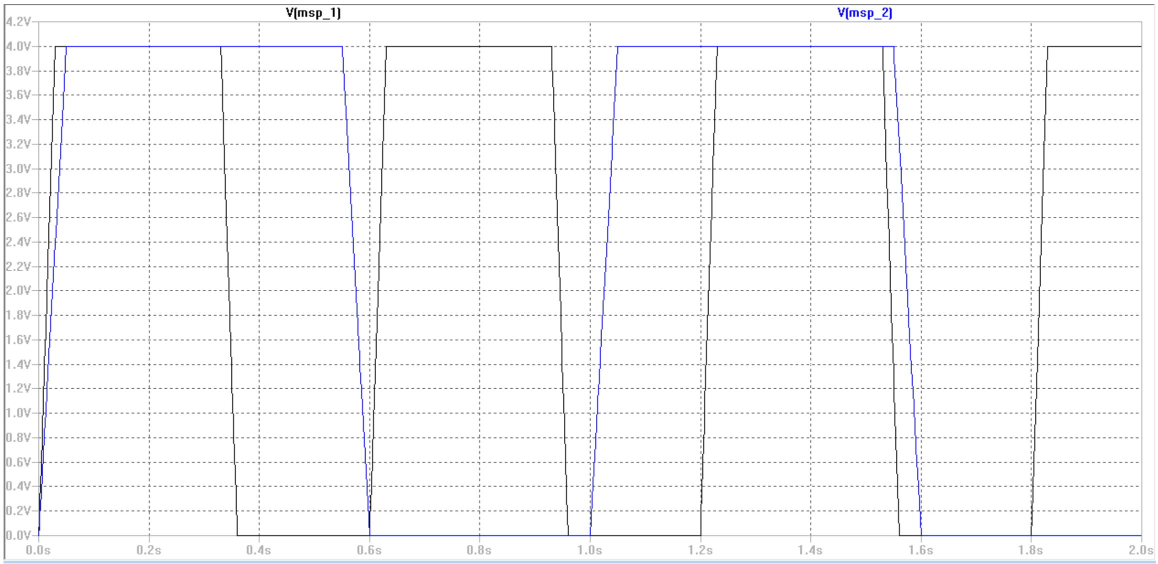

Figure 5 Voltage Signals Waveforms Measured at both Nodes of the Load Terminals of the H-bridge

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.

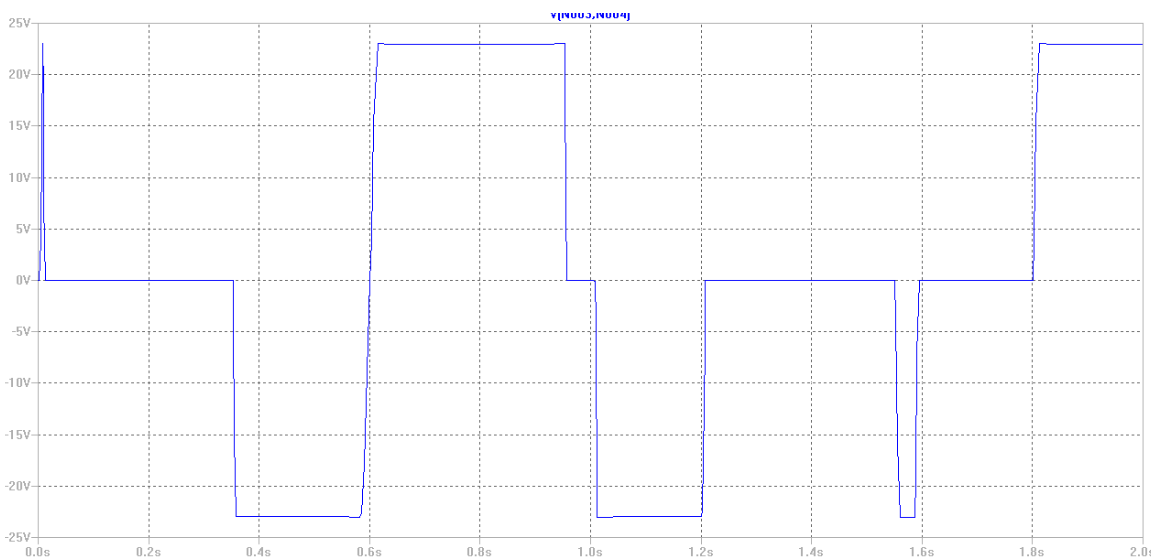

Figure 6 Simulated Output Voltage Waveform of the H-bridge

3.4 Small Component Voltage Supply

The MSP430 is a low voltage microcontroller device, capable of operating using a 5 volt source. Designing a buck converter to convert from the 24 volt battery to 5 volts was beyond the scope of this project and achieving 5 V through a resistive divider would be inefficient. Therefore, we chose to incorporate a 4.5 volt battery pack from three AAA batteries and is used to supply the sensors, comparator chip and MSP430. The difference of 0.5 V from the nominal voltage did not significantly change the effectiveness of the h-bridge because the threshold voltage is approximately 2 volts.

3.5 Functional Decomposition Level 0 Block Diagram

The level 0 block diagram depicted in Figure 7 highlights the main input and output of the entire system. The system takes in sunlight as its input. Later, the system outputs LED light.

Table 3 explains the input and output of the system and explains the diagram’s functionality.

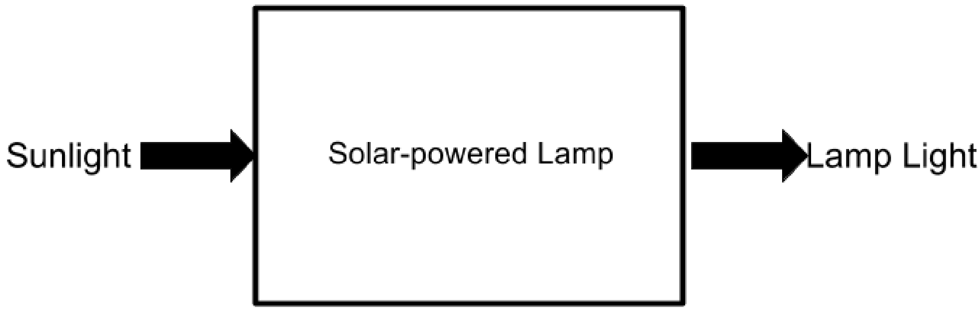

Figure 7 Solar LED Street Light Level 0 Block Diagram

Table 3 Solar LED Street Light Level 0 Functional Requirements Table

Module	Solar-Powered Street Lamp
Inputs	Sunlight
Outputs	Lamp Light
Functionality	The device takes in daylight and stores solar energy within the system. Light emits from the system in accordance to the brightness it receives.

3.6 Functional Decomposition Level 1 Block Diagram

The level 1 block diagram of **Error! Reference source not found.** 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 **Error! Reference source not found.** outline the Level 1 block diagram modules and explain the module's inputs, outputs and functionality

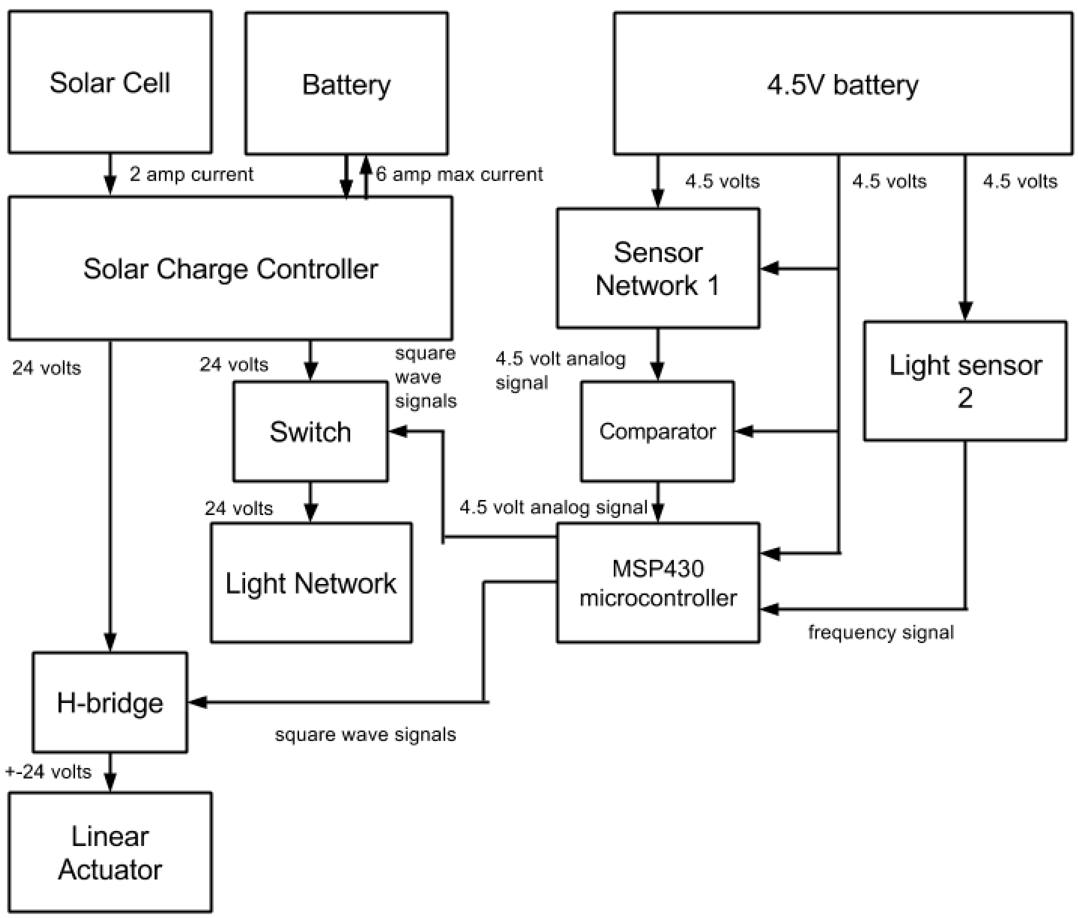

Figure 8 Solar LED Street Light Level 1 Diagram

Table 4 Solar Panel Inputs, Outputs and Functionality

Module	Solar Panel
Input	-Sunlight
Output	-Current to 24V battery

Functionality	The solar panel takes sunlight as an input and converts it to current. The 24 V battery receives the current output

Table 5 Ambient Light Sensor Inputs, Outputs and Functionality

Module	Light Sensor Network 1
Input	-Sunlight - 5V source Power 4.5 volt battery
Output	-Voltage waveform to comparator between 0 and 5 volts
Functionality	The ambient light sensor responds to incoming light. The sensor outputs a current, proportional to the incoming light

Table 6 Voltage Regulator Inputs, Outputs and Functionality

Module	Light Sensor 2
Input	- Power from 4.5V battery
Output	- 5V magnitude square wave signal sent to microcontroller
Functionality	The light outputs a square wave whose frequency is proportional to the amount of light observed. The signal is later utilized by the microcontroller

Table 7 Comparator Inputs, Outputs and Functionality

Module	Comparator
Input	-Three Ambient light sensor signals - 5V signal from Voltage Regulator
Output	-Voltage waveform to MSP430

Functionality	The comparator detects if either side mounted sensor detects a higher amount of light than the center sensor. If the center magnitude is exceeded, the sensor outputs a "high" signal to the microcontroller. The comparator outputs a square wave to the microcontroller.

Table 8 H-Bridge Inputs, Outputs and Functionality

Module	H-bridge
Input	-Two control signals from the MSP430 microcontroller -24 volt supply used as the rail voltage
Output	-Positive or negative 24 volt supply to linear actuator
Functionality	The h-bridge is a dc-dc type converter that inverts a dc signal. The h-bridge supplies a voltage magnitude of 24 volts and supplies voltage to the linear actuator

Table 9 MSP430 Microcontroller Inputs, Outputs and Functionality

Module	MSP430
Input	-Two comparator waveforms -5 V from 4.5 volt battery -Ambient Light sensor waveform
Output	-Control signal to switch above linear actuator -Control signals to the h-bridge
Functionality	The microcontroller takes a 5V supply voltage. The MSP430 Microcontroller takes in both the ambient light sensor's frequency output and the comparator outputs. The comparator result alerts the MSP430 which

	direction has the most light. The microcontroller also outputs two signals to the h-bridge circuit and determines what polarity voltage the actuator will sense. The second sensor indicates when the light is too dim. The microcontroller outputs the “turn on signal” to the switch.

Table 10 24 V Battery Inputs, Outputs and Functionality

Module	24 V Battery
Input	-Solar panel current
Output	-Voltage to microcontroller, comparator, ambient light sensors, actuator and LED Light Network
Functionality	24V Battery takes in the solar panel voltage and stores energy during the day. The Battery supplies voltage to all other components including the microcontroller and the LED light network.

Table 11 Actuator Inputs, Outputs and Functionality

Module	Linear Actuator
Input	-Voltage Signal from 24 V battery
Output	-Mechanical motion
Functionality	The actuator takes in a 24 V supply. The actuator produces motion to move the solar panel.

Table 12 LED Light Bulb Input, Output and Functionality

Module	Led Light Network
Input	-Voltage supply from 24 V battery through NMOS switch
Output	-Light
Functionality	The 24 V battery powers the LED Light Network. The control signal from the MSP430 determines when to turn on the switch

CHAPTER 4 Test Plans

4.1 Solar Panel Charging

The voltage of the battery must ideally maintain a constant 24 volts. The Morningstar charge controller handles appropriate trickle charge from the solar panel to the batteries and prevents the batteries from overcharging, resulting in battery life degradation. We determine the battery's discharge rate by disconnecting the solar panel from the controller and discharging the batteries through the light bulb. We determine the time needed for the batteries to fully charge by monitoring the time from the solar panel is connected until the green light status on the charge controller.

4.2 Sun-tracking capability

The sensors, microcontroller, and linear actuator cover the integral parts of the system's sun-tracking ability. The sensors placed at 45 degree angles from the face of the solar panel capture a wide range of light input. The comparator output from the LMC662CN chip indicates which direction contains the most light. The microcontroller operates the switching circuit and controls the linear actuator. The linear actuator requires both positive and negative voltages to either extend or retract. As a result, an H-bridge circuit handles the voltage polarity required by the actuator. If the center sensor receives the most light compared to the side sensors, the system remains idle. The voltage on the actuator determines how fast the actuator moves. A smaller voltage value is more desirable for slow operation of the actuator.

The linear actuator has only two leads for a voltage input signal. Since the device outputs no control information, we regulate the device's operation with set operation times. To account for the possibility that the panel would like to rotate past its limit, the microcontroller activates the actuator for 1 minute every 30 minutes. This timing constraint prevents deep battery discharge and conserves the current supplied to the h-bridge and linear actuator.

4.3 Light Sustainability

The light source chosen has built-in voltage regulation. The light source can operate continuously as long as it draws enough current to illuminate the LEDs. The resistance of the light is calculated such that the supply voltage is appropriate to provide the minimum current necessary for successful operation. Operating the light at minimum current increases total nighttime operation and increases light sustainability.

4.4 Battery Conservation

The microcontroller plays a large role in battery conservation. The microcontroller is responsible for activating the switches and connecting the light and linear actuator to the battery voltage. The linear actuator and the light consume the most power to operate. However, we plan to write the MSP430 code such that the linear actuator and the light never activate at the same time; therefore, neither draws current from the batteries simultaneously which may exceed the maximum safe current drawn from the batteries.

The battery voltage far exceeds the nominal voltage of the MSP430 and the four sensor components. It is impractical for us to use a resistive divider to step down the voltage from 24 to 5 volts to satisfy the MSP430 voltage requirement. This implementation into the system experiences a lot of heat and energy loss as a result. In addition, designing a buck converter requires more time than we expect to use to complete this project. We implement a small secondary battery back for the smaller devices.

Chapter 5 Development and Construction

The major components of construction include the solar panel mounting hardware, the base for the system, the rotation mechanism and the sensor network.

The solar panel pole requires some adjustment because pole starts as a straight 3 foot pole. A 30 degree notch cut 1.25 feet from the top of the pole, shown in Figure 9, allows the pole to bend into a 150 degree angle. The solar panel mounts to the top, angled piece of piping resulting in a tilt, 30 degrees from vertical. A mounting screw, shown in Figure 10, attaches to a flat arm piece through resistance welding and the arm piece fastens itself 6 inches from the bottom of the pole. The screw fits through the arm of our linear actuator and serves as the rotation mechanism for the system.

Figure 9 Photo of Modified Metal Pole

Figure 10 Photo of Movement arm on Metal Pole

A durable and sturdy base houses and protects all sensitive components. The battery, charge controller, microcontroller and linear actuator fit within a 2 foot by 2 foot by 10 inch, square-shaped plywood base, shown in Figure 11. The base also contains the lazy susan hardware to achieve the solar panel rotation. The components fit within the base such that the rotation of the pole avoids contact with the other devices.

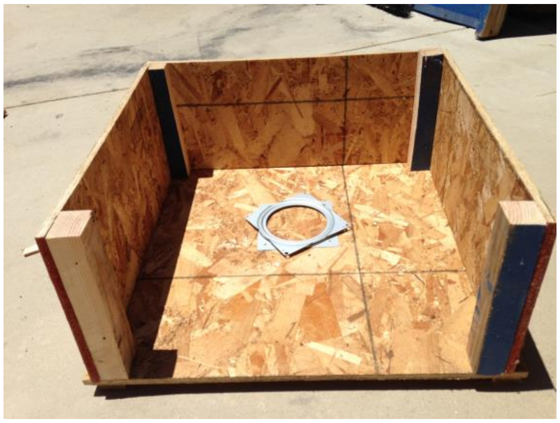

Figure 11 Photo of Wooden Base for Component Housing

Figure 12 Close-up Photo of Internal Components of Base Housing

The lazy suzan, shown in Figure 12, attaches itself to an intermediate wood square and attaches to the floor of the base with nails. A metal base bolted above the wood square houses the solar panel pole. The linear actuator mounts upon a wood block using a bolt and the block attaches to one of the base's walls with nails. The bolt gives the actuator freedom to rotate left and right along with the movement of the actuator arm.

The sensor network consists of our h-bridge circuit and the four light sensors. The soldering of the h-bridge and sensor components was easily completed. The h-bridge components fit compactly on a mounting board within a 2 inch by 2 inch square area. The sensors were soldered to smaller boards, affixed to clips and placed along the lower edge of the solar panel. Long leads join the outputs of the sensors and the battery to the microcontroller; however, the leads are kept as short as possible and flush to the piping to avoid signal loss and possible damage.

Figure 13 Photo of Sensors Mounted onto Solar Panel

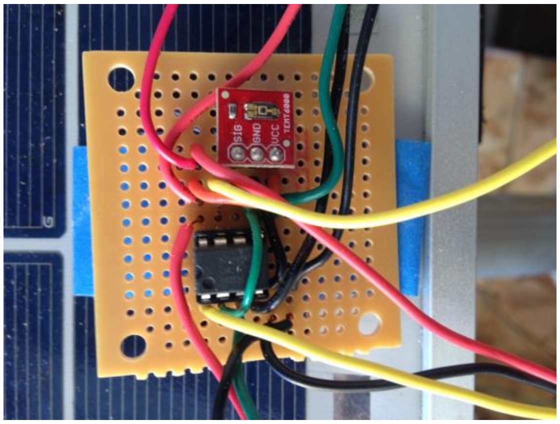

Figure 14 Photo of Center Sensor and Comparator Chip

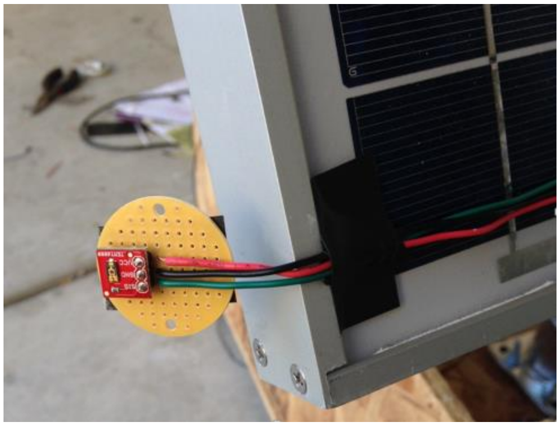

Figure 15 Photo of Side Sensor Mounted 45 Degrees from the Face of the Solar Panel

Figure 16 Photo of Secondary Battery Pack

Our compact system emulates all the essential functions of a larger, more practical system. A larger budget and more development time would allow a more implementable project.

CHAPTER 6 Integration and Test 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 Figure 17 and Figure 18 below.

Figure 17 Photo of Fully Constructed Project with Base Left Open For Observation

Figure 18 Close-up Photo of 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 moves 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.

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.

CHAPTER 7 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.

REFERENCES

[1] R. Ford and C. Coulston, *Design for Electrical and Computer Engineers*, McGraw-Hill, 2007, p. 37

[2] *IEEE Std 1233, 1998 Edition*, p. 4 (10/36), DOI: 10.1109/IEEESTD.1998.88826

IEEE Articles

[3] 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 Conference (DUE), 2012 Proceedings of the 20th* , vol., no., pp.111,115, 3-4 April 2012, URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6198219&isnumber=6198200

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 similar to our project. Authors R.D. Nell represents the Department of Electrical Engineering in Cape Peninsula University of Technol, South Africa.

[4] 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 photovotaics. 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.

<u>Online Resources</u>

[5] 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.

[6] 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.

[7] 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.

[8] 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/>.

[9] "Eartheasy." *LED Light Bulbs: Comparison Charts*. EarthEasy. Web. 14 Nov. 2014.
<http://eartheasy.com/live_led_bulbs_comparison.html>.

U.S. Patent

[10] 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.html&r=25&f=G&l=50&co1=AND&d=PTXT&s1=photovoltaic&OS=photovoltaic&RS=photovoltaic

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

[11] 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.

[12] Texas Instruments, "MSP430F15x, MSP430F16x, MSP430F161x MIXED SIGNAL MICROCONTROLLER," MSP430 datasheet, Oct. 2002 [Revised Mar. 2011].

Books

[13] 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

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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. It contains several references for each solar panel project.

Standards

[19] Bureau of Street Lighting Design Standards and Guidelines, BSL Standard, 2007.

MISCELLANEOUS

[20] PG&E. (2008) *LED Street Lighting*," [Online] Available: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_sf-streetlighting.pdf

[21] FAU Astronomical Observatory. (2013) *Light Pollution Hurts Our Economy and Our Resources* [Online] Available: http://physics.fau.edu/observatory/lightpol-econ.html#Total_US_Wasted_Lighting

[22] U.S. Energy Information Administration (2014) *Electricity Data* [Online] Available: http://www.eia.gov/electricity/data/browser/

[23] E. McLamb (2011, September 6) *Fossil Fuels vs Renewable Energy Resources* [Online] Available: http://www.ecology.com/2011/09/06/fossil-fuels-renewable-energy-resources/

[24] L Hutchinson (2012) *Turning Night Into Day: Light Pollution's Impact on Wildlife* [Online] Available: http://lighting.com/light-pollution-wildlife/

[25] Institute of Electrical and Electronics Engineers, Inc.. (2006). *Code of Ethics IEEE,* http://www.ieee.org/. Retrieved at July 28, 2009, from the website temoa : Open Educational Resources (OER) Portal at http://www.temoa.info/node/23284

Appendix A – Analysis of Senior Project Design

Project Title: Sun-Tracking Solar-Powered LED Street Light
Student's Name: Wesley Ballar & Harrison Wong
Advisor Name: Bryan Mealy

Summary of Functional Requirements

The complete system solely uses solar power to track the sun and provide illumination. The system's solar panel takes in sunlight and charges its battery. The charge controller regulates battery charging and maintains optimal battery usage. The controller also acts as a switch to connect the battery to the load. The system detects light levels and adjusts its position for optimum solar energy harvesting during the daytime. When the system no longer detects optimum sunlight, the device outputs light through the LED bulb. The system requires no human input to operate once installed.

Primary Constraints

Significant challenges to the project include calculating and predicting the atmospheric conditions of the desired implementation area. The device ideally produces light every night of the year and therefore the sun must supply enough energy for this purpose. Since sunlight varies throughout the year, the device may not generate enough energy for its battery one or more nights at a time. Also, although the batteries indicate a certain amp-hour output, the charge controller independently determines safe operation and therefore the light cannot sustain itself as prescribed in the requirements.

The voltage requirement was difficult to fulfill. Component tolerances did not always match up and also inhibited project progress. The h-bridge components failed under the voltage conditions supplied by the system during testing of the linear actuator. We constructed several iterations of the h-bridge and implemented them in the design until finding success.

The cost restriction also limited the components chosen for the product. The device begins to profit only after several years of service. If more money is allocated to the product for more efficient design, a longer profit time would result.

Economic

Several economic factors play a role in the production of the LED Street Light. Capital generated by this device derives from system production, shipping and maintenance. Development and distribution affect manufacturers, truck drivers and delivery crew. Larger entities exist that have a larger stake in the project as well. Electrical measuring equipment companies have a stake in the maintenance of the products. Local energy committees benefit by implementing self-sustaining, eco-friendly arrangements in their cities.

Costs accumulate during initial product production and assembly and large costs may result during widespread retrofit projects. Using PG&E's San Francisco case, the projected payback of a large retrofit to a city amasses after about fourteen years of full time service to the community [20]. The original cost of the prototype Solar LED street lamp is $549.64; the Cal Poly EE Senior Project fund pays for most of the cost of this project and we cover the remaining fees. The total cost of the components increased due to shipping and taxes; different purchasing methods may decrease project cost and result in shorter payback periods. display the initial Gantt charts for the development of the first LED Street Lamp. Figure 20 shows the Gantt chart for the actual development cycle Figure Primary investors, including state governments, would accumulate revenue. Products take about one month to produce and product operation spans approximately 16 years [20].

After project completion, the San Luis Obispo community or Cal Poly campus may utilize and implement the design. With successful operation, Cal Poly or San Luis Obispo can save money on their electricity bill and encourage neighboring cities or college campuses to use the product as well.

Table 13 Gantt Chart Member Responsibility Legend

Member Responsibility	Wesley	Harrison	Both Members
Gantt Chart Color			

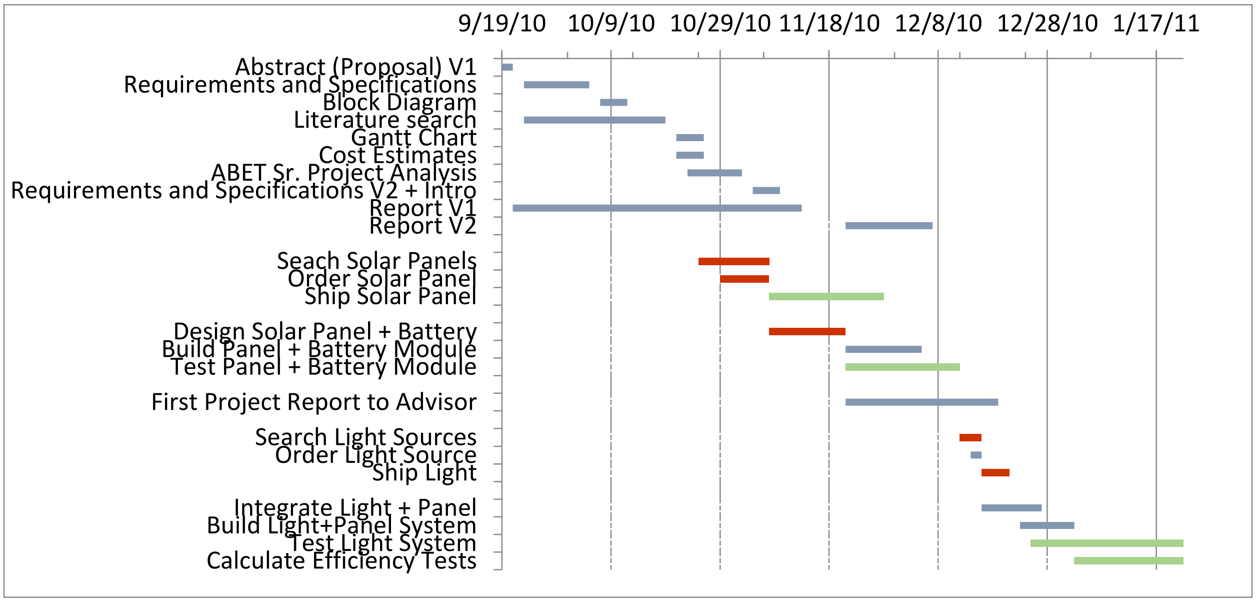

Figure 19 Predicted Solar LED Street Light Fall 2014 Gantt Chart

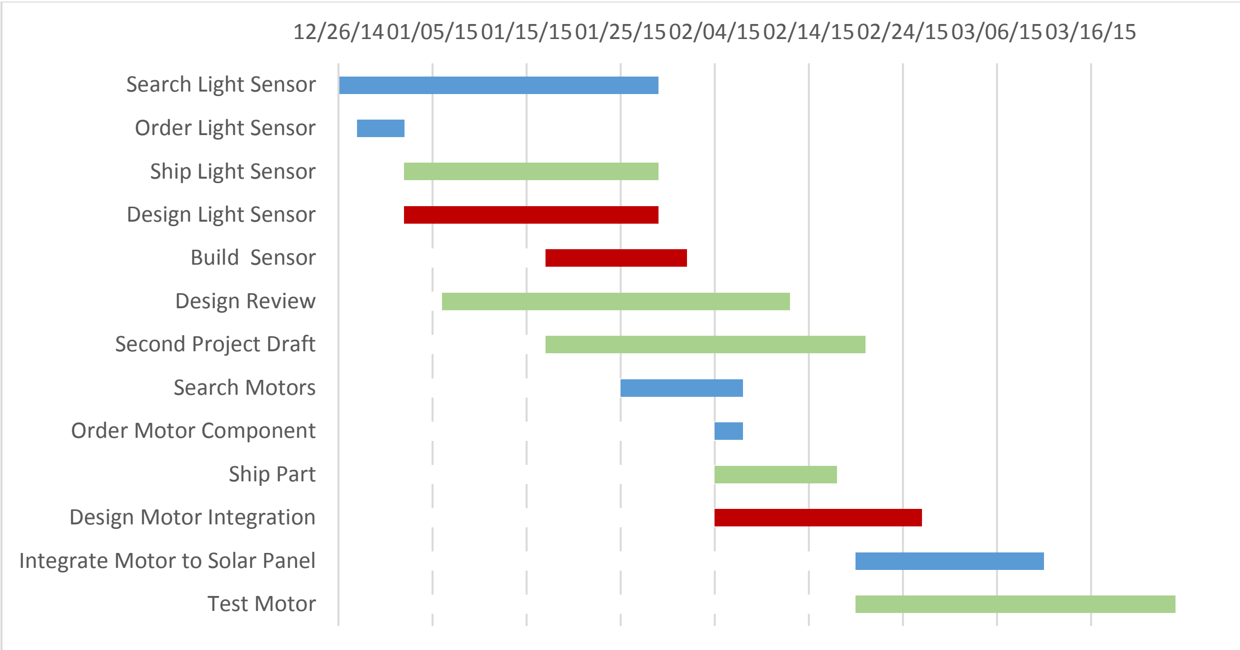

Figure 20 Predicted Solar LED Street Light Winter 2015 Gantt Chart

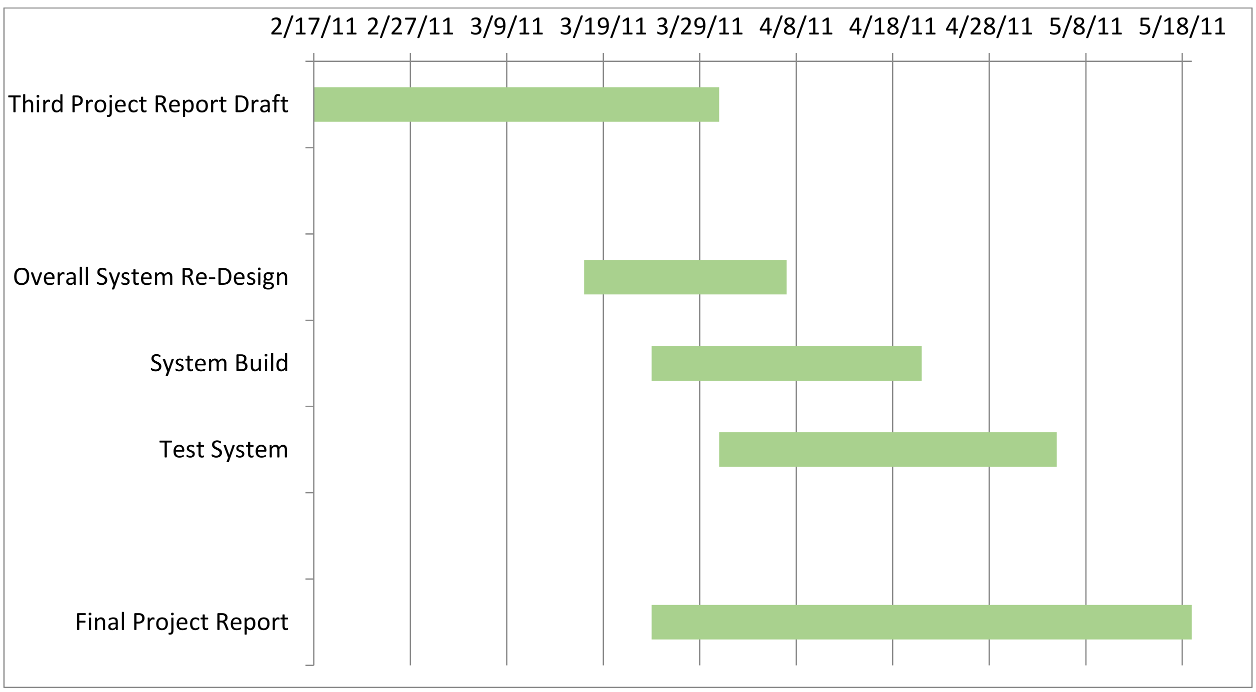

Figure 21 Predicted Solar LED Street Light Spring 2015 Gantt Chart

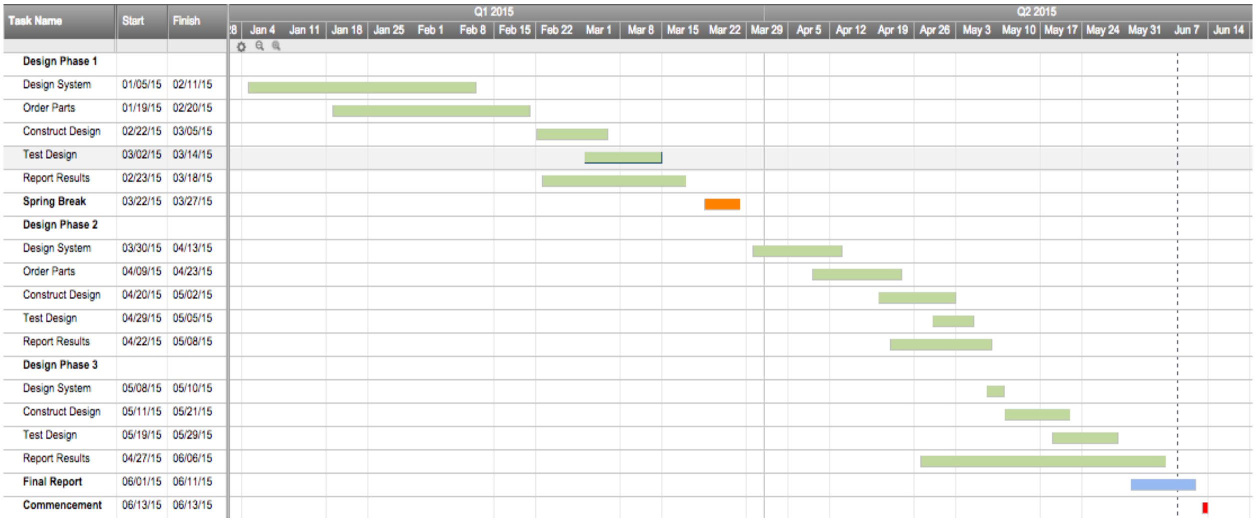

Figure 22 Actual Project Timeline Gantt Chart; Responsibility Color Legend (Table 12) Not Used Here

Table 14 Project Component Cost Estimates Table and Description

Component	Quantity	Unit Cost (U.S. dollars)	Extended Price	Description
Solar Panel	1	239.68	239.68	64 watt, 32 V, Solar Tech Power brand solar array
Battery	2	17.28	34.55	ExpertPower® Rechargeable 12V 7AH Sealed Battery
Linear Actuator	1	69.58	69.58	12-24 volt 8 inch stroke Everest Parts brand
Light Sensor	4	4.95	19.8	TEMP6000 Vishay Brand Ambient Light Sensor
Microcontroller	1	9.99	9.99	MSP430 Launchpad Microcontroller
LED Light	1	80.70	80.70	12-32 Volt, 2500 lumen Larson Electronics Brand LED Light Bulb
Charge Controller	1	92.34	92.34	24 volt Morningstar brand charge controller
Op-Amp		0.50	0.50	LMC662CN Texas Instruments brand CMOS Dual Operational Amplifier
Soldering Boards		4.50	4.50	Prototyping Perforated Board
Labor Cost		600.00	600.00	The labor expenditure includes production of parts straight out of factory, individual component
Total Cost			1149.64	

Commercial basis

Consumers buy our solar-powered lights in large quantities and use them indefinitely for city usage. The company may sell approximately 1000 units per year if commercially manufactured. For simple payback calculation, component research prices found in Table 14 estimate a total project cost of a minimum of 549.64 dollars, neglecting labor cost. A single light earns back about $40 per year in energy savings according to LED studies. Using these numbers, profit occurs after the first 14 years, after the revenue meets the initial payment. This number of years may increase depending on maintenance costs.

An LED street light retrofit conducted by PG&E contains maintenance costs from $7.78 to $10.13 dollars per year considering worst and best case LED scenarios. With this maintenance cost factored in, payback takes between 15 years and 17 years to pay back.

With labor considered, the labor cost is estimated from a 30 dollar per hour rate and a production time of 20 hours. This total results in $600 of labor expenditures. However, on a commercial basis, the city and regional planning teams primarily contribute to the funding necessary for product development.

Environmental

The utilization of the environment improves with the implementation of the product. This streetlamp does not rely on grid utility power to generate light. Each self-sufficient light independently determines its conduction time. The city level environment becomes more efficient by using less energy from the utility company supplying the power. The sun supplies virtually unlimited amounts of clean energy unlike fossil fuels [23]. The product solely relies on the solar energy provided in a given area.

Because of its implementation and light emission, the product affects other animal species. The implementation on lampposts may affect bird and populations [24]. For bird species safety, glare and reflection reduction occur by angling and focusing the LED light downwards, decreasing overhead light pollution.

Manufacturability

No significant manufacturing challenges greatly hinder this project. Commercially available parts make up this device and have reliable documentation for reproduction. Component sizing and design layout make up minor project issues. Component tolerances also affect successful product operation and reduce sensor accuracy and system efficiency.

Sustainability

Inconsistent weather conditions negatively impact the device. Overcast days, rain and other extreme weather phenomena disrupt system usage. The Sun-Tracking Solar-Powered LED Street Lamp's waterproof design protects against moisture and its external housing protects against high wind speeds. This project decreases the public's reliance of power company's energy reserves; it uses pure sunlight and solar energy to power its lights and motion apparatus.

Different types of light bulbs and lighting sources can improve overall system efficiency and light output. Upgrading the design includes two axis motion, more powerful LED lights, better microcontroller performance and better solar panel efficiency. Regulation of light intensity and implementing a dimming capability also improves sustainability and usage. These upgrades require more funding to acquire, assemble and test. More features prove more costly to the product.

Ethical

Ethical concerns arise during use of the product. Concerns may include obstruction of public spaces especially in small communities. Manufacturing problems arise when allocated outside the United States or outsourced to cheaper labor sources. Our company discourages perpetuating the unethical treatment of child labor and other forms of forced service. The product does not use conflict materials or resources in its design. The LED Street Lamp uses sustainable and recyclable components including the sensor and solar panel. Reliable, trusted companies produce these components.

Ethical egoism applies to this product's ethical framework. Our company ought to act in self-interest utilizing the sun's natural resources because many companies typically underutilize solar energy. This nearly-unlimited natural resource proves vital in energy management and improving the energy consumption in the United States.

Kant's Categorical Imperative also applies to our project's goals and objectives. People should take it upon themselves to improve the environment as a universal standard. If by using solar energy, the environment's condition improves with reduction in carbon emissions and ecological damage, more communities should adopt this technology. It is the company's duty to actively improve existing technology for the benefit of ecology.

This project composes its ethical validity using the IEEE code of ethics. Our group accepts responsibility to make decisions concerning the public using credible standards, produces products with no bias of all forms of discrimination and rejects all forms of bribery. Our policy maintains honesty about our claims and statistics, avoids injuring the property, reputation and employment of our affiliates and remedies conflicts of involved parties [25].

Health and Safety

Standard health and safety standards necessitate proper manufacturing and device security. The design of our device follows the Bureau of Street Light Design.

The streetlamp design includes a 15 pound solar panel and must resist harsh weather. A faulty setup can lead to the device falling from the post and injuring passersby. The battery must also secure neatly and away from human intervention. Tampering with the battery or microcontroller causes bodily damage and device damage. The device design considers safety to other species as well. The design eliminates exposed wiring or sharp edges that could damage animals interfering with the device [19].

Social and Political

Local state governments invest the most in this project. These constituents help the reduction of electrical utility costs by endorsing and implementing our device in a wide spread area. Direct stakeholders include our advisor, and state governments. Indirect stakeholders include pedestrians and other citizens who have direct usage of the product. Our direct stakeholders benefit monetarily if our product does well on a commercial market by reducing emissions and providing adequate service. Conversely, pedestrians benefit socially, conducting outdoor communal events during nighttime hours enabled by our technology.

Stakeholders may not benefit if the product does not perform all enumerated specifications or if malfunctions occur during use. Actual, physical harm may come if manufacturing processes violate standard safety measures. Economically, direct stakeholders pay directly towards the project while indirect stakeholders pay taxes and benefit from the public use of the product.

The cost savings from the product result in better budgeting and better allocation of tax funds for other municipal projects. Governments decide funds on a federal level. The product causes inequality if the device is not distributed evenly across an area.

Development

New techniques learned during the project include pulse width modulation and comparator usage. Pulse width modulation determines brightness control the of the LED light network. This technique accomplishes dimming ability. Comparator design enables light switching. This component allows the device to have threshold on and off trigger points.

The literature search primarily aids in the development of our project. The research leads to component datasheets, previous full-scale projects and nationally published statistics central to this device.

Appendix B – Software

```
//****************************************//
// LCD, Time, Frequency
// Senior Project
//****************************************//

#include <msp430.h>


#define TRUE 1
#define FALSE        0

// LCD Defines
#define NIBBLE                  1
#define LCD_CLEAR_DATA                  0x01
#define LCD_CLEAR_CNT           0X0
#define LCD_RETURN_DATA                 0x02
#define LCD_RETURN_CNT                  0x0
//#define LCD_ENTRY
#define LCD_DISPON_DATA                 0x0F
#define LCD_DISPON_CNT          0x0
#define LCD_DISPOFF_DATA        0x08
#define LCD_DISPOFF_CNT                 0X0
#define LCD_CURS_R_DATA                 0x14
#define LCD_CURS_R_CNT                  0x0
#define LCD_CURS_L_DATA                 0x10
#define LCD_CURS_L_CNT          0x0
#define LCD_SHIFT_R_DATA        0x1C
#define LCD_SHIFT_R_CNT                 0x0
#define LCD_SHIFT_L_DATA        0x18
#define LCD_SHIFT_L_CNT                 0x0
#define LCD_FUNC_8_DATA                 0x38
#define LCD_FUNC_8_CNT          0X0
#define LCD_FUNC_NIB_DATA       0x28
#define LCD_FUNC_NIB_CNT        0X0
#define LCD_CGRAM_DATA                  0x20
#define LCD_CGRAM_CNT           0x0
#define LCD_DDRAM_DATA                  0x80
#define LCD_DDRAM_CNT           0x0
#define LCD_BUSY_CNT            0x1
#define LCD_ADDR_CNT            0x1
#define LCD_READ_CNT            0x2
// ASCII Letter Codes
```

```
#define ASCII_C                         0x43
#define ASCII_c                         0x63
#define ASCII_d                         0x64
#define ASCII_E                         0x45
#defineASCII_e                          0x65
#define ASCII_H                         0x48
#defineASCII_k                          0x6B
#define ASCII_l                         0x6C
#define ASCII_o                         0x6F
#define ASCII_P                         0x50
#define ASCII_R                         0x52
#define ASCII_r                         0x72
#define ASCII_s                         0x73
#define ASCII_W                         0x57
#define ASCII_EXCLAIM                   0x21
#define ASCII_SPACE                     0x10
// LCD Location defines
#define LINE1_START                     0x00
#define LINE2_START                     0x40

//initiallize global variables
unsigned int edge1 = 0x0000;
unsigned int edge2 = 0x0000;
int count = 0;
float period = 0 ;
char sp[5] = "    ";
float frequency = 0;
unsigned int cycles = 0;
unsigned int edgeCount = 0;
char stest[6] = "     ";
float current = 0;
int i= 0;
float cycleAvg = 0;
float light = 0;

// Function Prototypes
void mainLoop();
void initLCD(int nibble);
void writeLCD(int control, int data, int nibble);
int readLCD(int control, int data, int nibble);
void writeASCIIAtLocation(int character, int location, int nibble);
void writeASCII(int character, int nibble);
void clearLCD(int nibbl);
int readData(int control, int nibbl);
```

```
void waitForBusyFlag(int nibbl);
void writeString(char string[], int len, int nibbl);
void writeStringAtLocation(char string[], int len, int location, int nibbl);
void i_toa (unsigned int i, char *buf, int len);
void frequencyCalc();
void currentCalc();
void fcCalc();


// Main
int main(void) {

  WDTCTL = WDTPW | WDTHOLD;        // Stop watchdog timer

  //Set MCLK to 1Mhz
  if (CALBC1_1MHZ==0xFF) while (1);  // If calibration constant erased, do not load, trap
CPU!!
  DCOCTL = 0;                               // Select lowest DCOx and MODx settings
  BCSCTL1 = CALBC1_1MHZ; // Set range
  DCOCTL = CALDCO_1MHZ;      // Set DCO step + modulation

  //Time A set up
  TACTL = ID_3 + TASSEL_2 | MC_2 | TAIE | TACLR;     // Time A uses SMCLK,
continuous contmode sets to 125KHz
  TACCTL0 = CM_1 + CCIS_0 + SCS + CAP +CCIE;  //Captures on rising edge of input signal
on port CCIxA P1.1

  P1SEL |= 0x02;  //sets P1.1 as input for timer interrupt. input for tone detector

// Configure I/O Port Directions
  P1DIR = 0XF0;     //P1.4-7 are data bits for nibble mode DB11-14: set as outputs.
  P2DIR = BIT0 | BIT1 | BIT2; //| (P2DIR & ~BIT3); // Pins 0-2 in port 2 are outputs. Control
bits for LCD. E/RS/RW. Pin 3 is an I
  // P2.0 - Output: R/W
  // P2.1 - Output: RS
  // P2.2 - Output: E
  // P2.3 - Input Tone Dector changes to P1.1



  // Initializations
  initLCD(NIBBLE);

  // Run program
```

```
   mainLoop();
CCTL0 = CCIE;
        CCR0 = delay;
        TACTL = TASSEL_2 + MC_2 + ID_3;
        _BIS_SR(GIE);
        _enable_interrupts();

        char freq[] = "FREQ:      Hz";
        P2DIR = 0xF0;
        P1OUT = 0x80;
        P2OUT = 0x07;

        write_char(' ');
                if((P1IN & 0x00) == 0x00)
                {
                        int i;
                        for (i = 0; i < 80; i++)
                        {
                                write_char(freq[i]);
                        }
                }
        return 0;
}

void mainLoop() {
        clearLCD(NIBBLE);
        __delay_cycles(25000);
     writeString("main", 4, NIBBLE);
        _BIS_SR(LPM0_bits + GIE);           // Enter LPM0 w/ interrupt
        //return;
}

//Port 2 interrupt servise Routine
/*#pragma vector=PORT2_VECTOR
__interrupt void Port_2(void) {

     //clearLCD(NIBBLE);
     //writeString("Port Interrupt", 13, NIBBLE);
     //__delay_cycles(25000);
     edgeCount++;
     //i_toa(edgeCount, stest, 5);
     //writeString(stest, 5, NIBBLE);
     //creates a time stamp at rising edge
```

```
	//clears interrupt flag and enables interrupts
	P2IFG = 0x00;

}*/

// Timer A0 interrupt service routine
#pragma vector=TIMER0_A0_VECTOR
__interrupt void Timer_A (void) {
 //clearLCD(NIBBLE);
 //writeString("interrupt", 9, NIBBLE);
 char tempFreq[3] = "  ";
 char tempFreq1[2] = " ";
 char tempRem[1] = "";
 char tempI[3] = "  ";
 int j = 0;
 float rem = 0;

 if(count == 0){
	   edge1 = TACCR0;
	   count++;
	}
	else if(count == 1){
	   edge2 = TACCR0;
	   cycles = edge2 - edge1;
	   //if(cycles>500){
	   //cycleAvg = (cycleAvg + cycles) / 2;
	   //i++;
	   //}
	   cycleAvg = (cycleAvg + cycles) / 2;
	   i++;
	   count = 0;
	   TACTL |= TACLR;
	   /*i_toa(i, tempI, 3);
	  writeString(tempI, 3, NIBBLE);*/
	}
 if(i == 20){
	   period = cycleAvg * 8; //must add units of us
	   frequency = (1000/ period) * 1000; // units Hz
	   frequency++;
	   if(frequency >= 39){
	     frequency++;
	     if(frequency >= 79){
	       frequency++;
```

```
    if(frequency >= 119){
      frequency++;
      if(frequency >= 159){
        frequency++;
        if(frequency >= 204){
          frequency++;
        }
      }
    }
  }
}
/*if(frequency <100){
  frequency= frequency *10;
  rem = frequency % 10;
  frequency = frequency/10;
  i_toa(frequency, tempFreq1, 2);
  i_toa(rem, tempRem, 1);
  writeString("F=",2,NIBBLE);
  writeString(tempFreq1, 2, NIBBLE);
  writeLCD(0X00; 0x2E, NIBBLE);
  writeString(tempRem, 1, NIBBLE);
}
else{
*/

//Converts frequency  to string to be written
i_toa(frequency, tempFreq, 3);
clearLCD(NIBBLE);
writeString("F=", 2, NIBBLE);
writeString(tempFreq, 3, NIBBLE);
writeString("Hz", 2, NIBBLE);
//}
fcCalc();
currentCalc();
while(j<5){
__delay_cycles(0XFFFF);
j++;
}

i = 0;
cycleAvg = 0;
TACTL |= TACLR;
 }
}
```

```
/*
void frequencyCalc(){
 char tempf[3] = "  ";
 //edgeCount--;
 frequency = edgeCount / 2;
 i_toa(frequency, tempf, 3);
 clearLCD(NIBBLE);
 writeString("F=", 2, NIBBLE);
 writeString(tempf, 3, NIBBLE);
 writeString("Hz", 2, NIBBLE);
 edgeCount = 0;
}*/

void fcCalc(){
 char tempLight[3] = "  ";
 unsigned int L = 0;
 /*light = (0.7738 * frequency) + 5.3899;*/ //light [fc] original
 //light = (0.78 * frequency) + 5.3899; //light [fc]
 light = 2.704 * frequency;
 i_toa(light, tempLight, 3);
 writeStringAtLocation("L=", 2, LINE2_START, NIBBLE);
 writeString(tempLight, 3, NIBBLE);
 writeString("fc", 2, NIBBLE);
}

void currentCalc(){
 char tempC[5] = "    ";
 unsigned int Cu = 0;
 current = ((86.99 * frequency) + 16.27); // scaled to nA
 /*if(current>9999){

 }*/
 i_toa(current, tempC, 5);
 writeString("I=", 2, NIBBLE);
 writeString(tempC, 5, NIBBLE);
 writeString("nA", 2, NIBBLE);
}


void writeString(char string[], int len, int nibbl) {

   if (!len) return;
```

```
  int i = 0;

  writeASCII(string[0], nibbl);

  for (i = 1; i < len; i++) {

     writeASCII(string[i], nibbl);

  }

  return;

}

void initLCD(int nibbl) {
         if(!nibbl){
                  __delay_cycles(20000); // wait 20ms
                  writeLCD(LCD_FUNC_8_CNT, LCD_FUNC_8_DATA, nibbl);
         // Set Function
                  __delay_cycles(37); // wait 37us
                  writeLCD(LCD_DISPON_CNT, LCD_DISPON_DATA, nibbl);
         // Display Set
                  __delay_cycles(37); // wait 37us
                  writeLCD(LCD_CLEAR_CNT, LCD_CLEAR_DATA, nibbl);
         // Display Clear
                  __delay_cycles(1520); // wait 1.52ms
         } else {
                  __delay_cycles(20000); // wait 20ms
                  // Send most significant nibble of FUNC_DATA
                  P1OUT = (P1OUT & 0x0F) | (LCD_FUNC_NIB_DATA & 0xF0);          //
Output data
                  P2OUT = (P2OUT & 0xF8) | LCD_FUNC_NIB_CNT;
         // Set RS/RW
                  P2OUT = P2OUT | 0x04;
                  // Set Enable
                  __delay_cycles(1);
                  P2OUT = P2OUT & 0xFB;
                  // Clear enable
                  __delay_cycles(1);
                  waitForBusyFlag(nibbl);
                  // Send the rest of the initialization commands
                  writeLCD(LCD_FUNC_NIB_CNT, LCD_FUNC_NIB_DATA, nibbl);
         // Set Function
                  __delay_cycles(37); // wait 37us
```

```
		writeLCD(LCD_DISPON_CNT, LCD_DISPON_DATA, nibbl);
	// Display Set
		__delay_cycles(37); // wait 37us
		writeLCD(LCD_CLEAR_CNT, LCD_CLEAR_DATA, nibbl);
	// Display Clear
		__delay_cycles(1520); // wait 1.52ms
	}
	return;
}

void writeLCD(int control, int data, int nibbl) {
	if(!nibbl) {
		P1OUT = data;
	// Output data
		P2OUT = (P2OUT & 0xF8) | control;				// Set
RS/RW
		P2OUT = P2OUT | 0x04;
	// Set Enable
		__delay_cycles(1);
		P2OUT = P2OUT & 0xFB;
	// Clear enable
		__delay_cycles(1);
		waitForBusyFlag(nibbl);
	} else {
		// Send most significant nibble
		P1OUT = (P1OUT & 0x0F) | (data & 0xF0);			// Output data
		P2OUT = (P2OUT & 0xF8) | control;				// Set
RS/RW
		P2OUT = P2OUT | 0x04;
	// Set Enable
		__delay_cycles(1);
		P2OUT = P2OUT & 0xFB;
	// Clear enable
		__delay_cycles(1);
		waitForBusyFlag(nibbl);
		// send least significant nibble
		P1OUT = (P1OUT & 0x0F) | ((data << 4) & 0x0F0);		// Output data
		P2OUT = (P2OUT & 0xF8) | control;				// Set
RS/RW
		P2OUT = P2OUT | 0x04;
	// Set Enable
		__delay_cycles(1);
		P2OUT = P2OUT & 0xFB;
	// Clear enable
```

```
		__delay_cycles(1);
		waitForBusyFlag(nibbl);
	}
	return;
}

void writeASCIIAtLocation(int character, int location, int nibbl) {
	writeLCD(0x0, location | 0x80, nibbl);				// setting DDRAM address to
location on LCD. Sets MSB.
	writeLCD(0x2, character, nibbl);				// writing character to
DDRAM
	return;
}

void writeASCII(int character, int nibbl) {
	writeLCD(0x2, character, nibbl);				// writing character to
DDRAM
	return;
}

void clearLCD(int nibbl) {
	writeLCD(LCD_CLEAR_CNT, LCD_CLEAR_DATA, nibbl);
	// Display Clear
	return;
}

int readData(int control, int nibbl)
{
	int oldP1DIR = P1DIR;
	int data = 0;
	if (!nibbl) {
		P1DIR = 0x00;				// Set Port 1 as an Input
		P2OUT = (P2OUT & 0xF8) | control;	// Output RS and R/W
		P2OUT |= 0x4;				// Turn on enable
		__delay_cycles(1);
		data = P1IN;				// Read the data
		P2OUT &= 0xFB;				// Turn off enable
		__delay_cycles(1);
	} else {
		P1DIR &= 0x0F;				// Set first nibble of Port 1 as an
Input
		P2OUT = (P2OUT & 0xF8) | control;	// Output RS and R/W
		P2OUT |= 0x4;				// Turn on enable
		__delay_cycles(1);
```

```
		data = P1IN & 0xF0;			// Read upper nibble
		P2OUT &= 0xFB;				// Turn off enable
		__delay_cycles(1);

		P2OUT |= 0x4;				// Turn on enable
		__delay_cycles(1);
		data |= (P1IN >> 4) & 0x0F;		// Read lower nibble
		P2OUT &= 0xFB;				// Turn off enable
		__delay_cycles(1);
	}

	P1DIR = oldP1DIR;				// Reset Port 1 direction

	if (control == LCD_BUSY_CNT)  data &= 0x80;			// keep only
the busy flag
	else if (control == LCD_ADDR_CNT) data &= 0x7F;			// keep only
the address

	return data;
}

void waitForBusyFlag(int nibbl)
{
	while (readData(LCD_BUSY_CNT, nibbl));
	return;
}

void writeStringAtLocation(char string[], int len, int location, int nibbl) {
  if (!len) return;
  int i = 0;
  writeASCIIAtLocation(string[0], location, nibbl);

  for (i = 1; i < len; i++) {
     writeASCII(string[i], nibbl);
  }
  return;
}
void i_toa (unsigned int i, char *buf, int len) {
	if (!len) return;
	int loc = len - 1;
	int rem;
	char a;
	while (i > 0 && loc > -1) {
		rem = i % 10;
```

```
		i = i / 10;
		switch (rem) {
			case 0:
				a = '0';
				break;
			case 1:
				a = '1';
				break;
			case 2:
				a = '2';
				break;
			case 3:
				a = '3';
				break;
			case 4:
				a = '4';
				break;
			case 5:
				a = '5';
				break;
			case 6:
				a = '6';
				break;
			case 7:
				a = '7';
				break;
			case 8:
				a = '8';
				break;
			case 9:
				a = '9';
				break;
			default:
				a = '#';
		}
		buf[loc] = a;
		loc--;
	}
}
```