Smart Solar Powered Street Light

ECE 445 Spring 2019

Design Document

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1 Introduction

1.1 Objective

Humanity currently faces many challenges that will depend on new developments and techniques to create a sustainable future. With one of the biggest challenges being energy consumption, there is a reason that renewable energy sources, such as solar and wind, are seeing dramatic growth. While the demand for energy is expected to keep increasing, there is a need for technological developments to improve the efficiency of devices that use large amounts of energy. In order to help with this problem, we are proposing a change to the current outdoor lighting systems to illuminate streetlights. With advancements in semiconductor technology, Light Emitting Diodes (LEDs) have become more suitable for various uses like outdoor lighting. [5] These lights have been known to have energy savings costs of around 50%, which is beneficial not only because they save energy but because half of the street lights in the U.S. are operated using public funding. [2] This means by using more efficient street light fixtures, less taxpayer money will need to be spent on the energy cost to utilize these lights.

Our group saw that there was an opportunity to make these LED street lights even more efficient by equipping them with solar panels/energy storage, along with sensors to indicate when there is someone approaching the vicinity. Using solar panels, the street lights will be able to harness their own energy during the hours that the light fixture is not functioning, and utilize that stored energy at night to illuminate our streets. Cost reductions in solar photovoltaics have led to an increase in the use of solar energy, which had lead to the development of different solar powered devices like street lights. These street lights are becoming more common, and have many advantages like using green energy, independence from the grid, and energy savings costs. They do come with disadvantages like higher installation cost, battery replacement cost, and susceptibility to reduced energy production from moisture, snow, or dust. In order to combat some of these challenges with solar street lights, we are proposing to use sensors in order to detect when the lights need to be on at full intensity and when they can idle at a lower intensity for energy savings. Also, we believe it would be beneficial for the design to incorporate a connection to the grid for safety reasons during events that the solar power generation does not meet the needs of the lighting system. This can occur when the solar photovoltaics are damaged or incapable of harnessing energy due to coverage or weather conditions (including areas with limited sunlight exposure).

1.2 Background

With the world's energy usage on the rise and not slowing down, there is a need to improve efficiency in order to reduce usage and operating costs. This rising trend can be seen in figure 1, coming from the U.S. Energy Information Administration. [10] One of the new technologies being implemented today is the solar street light that uses LEDs to illuminate streets, parking lots, and neighborhoods. We plan to incorporate this technology and develop a way for these lights to consume even less energy using doppler sensing. With this method, the streetlights will be even more energy efficient and cost-effective.

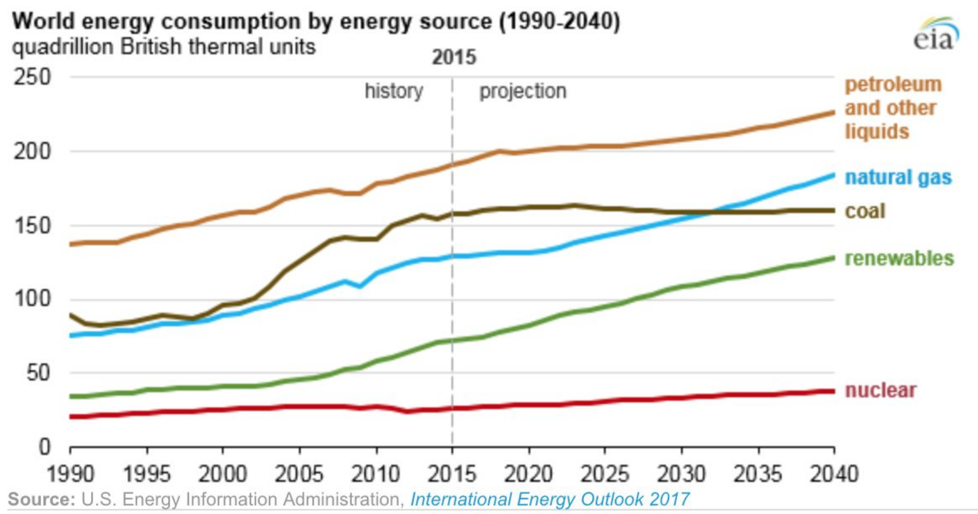

Figure 1: World Energy Consumption Trends and Projections

1.3 High-Level Requirements

- Streetlight must be able to supply and sustain at least 12 hours of continuous use with at least 0.3 cd/m^2 average luminance for the entire duration.
- Radar sensing method must be capable of detecting a typical United States road-legal passenger vehicle, cyclist, or pedestrian at a maximum of 40MPH speed toward the sensor within an average United States residential lane width of 12 feet.
- Intensity control must maintain at least an average 0.3 cd/m^2 (minimum legal luminance as specified by Illinois Department of Transportation [4]) at all times, while also increasing brightness as necessary based on radar detection.

2 Design

Each streetlight is responsible for generating electricity through its solar panel as well as being tied to the grid in order to make up for any deficiencies in solar generation. As a result, there are both AC and DC power inputs which must be taken into consideration before supplying power to the light fixture. On the control side, the voltage will be stepped down in order to operate the microcontroller and sensors necessary to correctly adjust intensity based on vehicle detection. Doppler sensors will communicate with the microcontroller in order to perform this intensity control.

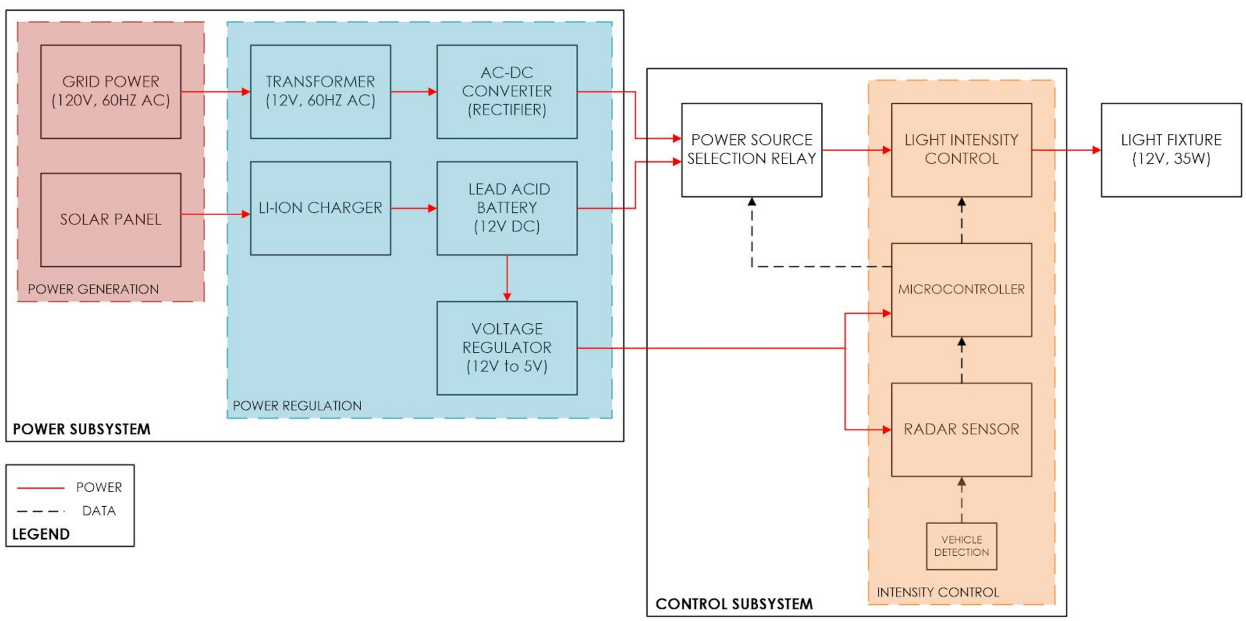

Figure 2: Block Diagram

2.1 Power Generation

Streetlights are powered by the local electrical infrastructure in various daisy-chain configurations. To make our streetlight proof-of-concept comparable to real street lights, grid connection capabilities will be built-in. The other form of generation will come from the DC solar panel on top of our streetlight; both of these forms of generation will provide a minimum of 40W for our light.

2.1.1 Solar Panel

A solar panel will be placed above our streetlight and angled in an appropriate manner. In the Northern Hemisphere, fixed panels should be oriented towards "true south". For increased panel efficiency, the angle would need to change based on the season (summer vs. winter). For our application, the panels will be oriented according to the summer scenario, which begins on March 30th and lasts until September 29. UIUC sits at a longitude of 40° and according to common solar panel tilt equations [1]:

$$(latitude\ *\ .93) - 21 = Tilt\ Angle \quad (1)$$

This results in a tilt angle of 16.2°. This angle and longitude result in an average Solar Insolation, according to [1], of $6.0\ \frac{kw}{m^2}$. It is also understood that this insolation must be verified and losses must be taken into account. With this angle, 75% of the energy output of the solar panels is possible when compared to a sun-tracking system. Ideally, the minimum solar panel top-side surface area is $8.833m^2$.

Requirement	Verification
The solar panel must be continuously held at the correct tilt angle of 16.2° with a tolerance of $\pm 2^{\circ}$.	The solar panel will be initially set up on its mounting structure, which will be built to support the weight of the panels and tilt them at $16.2^{\circ} \pm 2^{\circ}$. The angle will be measured prior to each test to confirm the desired angle is met.
The solar panel must be capable of properly supplying power in order to charge the 12V battery while maintaining proper circuit protection precautions.	Using a multimeter or another battery voltage monitoring device, observe the battery voltage at an initial state as well as in 30-minute intervals. A steady increase in battery voltage is a sign of charging, and the full-charge voltage may also be observed.

2.1.2 Grid Power

The other power source that our project uses is grid power, which will be converted from 120V AC to 12V DC. While a traditional streetlight in the United States typically operates at 50V, this causes unnecessary safety risks for our application, as well as requiring higher voltage ratings for components. The converter that will be used will be able to connect directly to a common 120V AC outlet and have a minimum rating of 40W.

Requirement	**Verification**
The converter must be capable of handling input of 120V AC at 60 Hz from the United States grid and convert this voltage to 12V DC with a minimum of 40W.	Since the input voltage is the responsibility of the supplying utility company, the converter must be able to accept the voltage supplied. The output of the converter will be verified by a test conducted in a laboratory setting with proper safety measures in place. The output voltage must be linear, with an average voltage of 12V and a tolerance of $\pm$0.1V.

2.2 Power Regulation

The solar panel will output DC power during the day in order to charge the batteries, which will output 12V DC, and the converter will also output 12V DC. Both these outputs will be inputs for the power relay, where the appropriate power input will be selected based on the state-of-charge (SoC) of the batteries.

2.2.1 Flooded Lead Acid 12V Battery

In order to utilize our solar photovoltaics, the energy harnessed during the day must be properly stored in order to power the street light during the night. To do this, we must use rechargeable batteries that can output 12V DC and store enough energy to run our lighting system for 12 hours continuously. Similar systems use lead acid, gel cell, or lithium-ion deep-cycle batteries in order to charge and discharge properly. This battery must be able to charge during the day and then run the lighting system for approximately 12 hours at night when the street lights are turned on. In order to achieve this, the approximate size of our battery would be 480 watt-hours (Wh). For the battery system, we will be using a charge controller to monitor how our solar panels charge the batteries.

Requirement	Verification
The battery must hold a charging voltage of 14.3V to 15V $\pm .2V$ at $25^{\circ}C$. It must also not drop below 11V $\pm .2V$. [16]	After the battery has been properly charged (or is currently at a sufficient charge), the output of the battery will be measured through the use of a voltmeter. This will be repeated in 30 minute intervals during the 12 hour period it needs to be running over night. The battery must hold a voltage of $14.3V - 15.0V \pm 0.2V$
From a full charge, the battery must be able to power the light fixture for a minimum of 12 hours continuously while maintaining the proper power to keep lights on.	When the battery is at full charge, it will be connected to the lighting system. From this time, it must power the light with the required luminance (0.3 cd/m^2) for at least 12 hours. To verify this we will use a Light Meter (Lux Luxmeter) to ensure our luminance stays within legal limit as stated before (.3 cd/m^2)

2.2.2 Charge Controller

Since the solar panels will charge the battery, a charge controller must be implemented to prevent overcharging. This device regulates the output voltage and current of the solar panel and is used to charge the battery. Solar panels have a voltage rating that is lower than the panel's theoretical maximum output. This is due to the panel being used under certain conditions, such as sunlight and temperature exposure. The charge regulator is used to make sure the desired output voltage for charging the battery is kept and also prevents damage to the battery during the charging process [8]. The charge controller also prevents power from the battery draining through the solar panels at night when the panels are not in use. The schematic for our charge controller can be seen in Figure 3. Equation 2 shows how we will determine at what current our batteries will charge. According to the data sheet "it is generally recommended to charge lead acid batteries .1-.3 times the batteries maximum current rating"[16].

$$I_{CHRG} = (Battery\ Max\ Current)(.3) \tag{2}$$

$$I_{CHRG} = (2.4\ A)(.3) = .72A \tag{3}$$

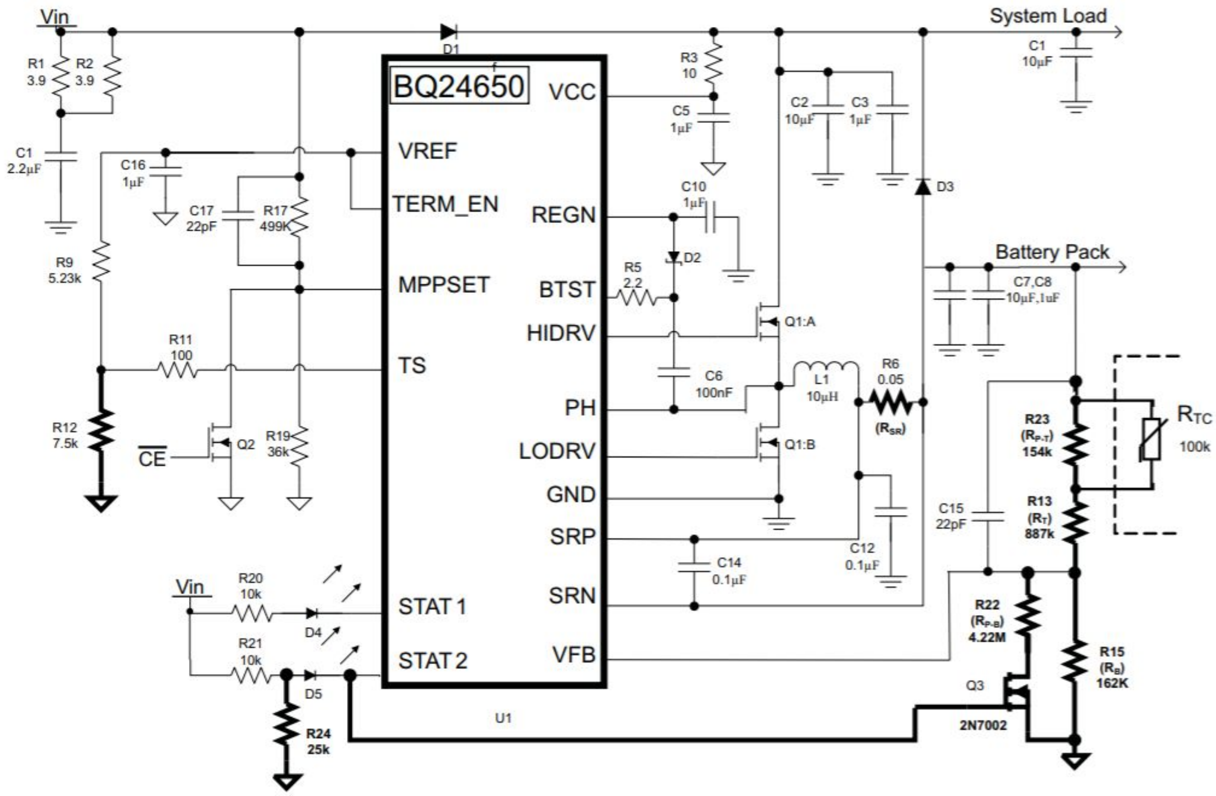

Figure 3: Schematic for Pulse Charging Lead Acid Battery[16]

Requirement	Verification
The charge controller circuit must be able to perform pulse charging operations for a sealed lead acid battery. It must also maintain rated voltages as said in 2.2.1 requirements.	We will create a constant voltage supply from lab to simulate our solar panels. Then use an o-scope to record the voltage and current and determine if the PCB matches the specs on the TI Spec. sheet. We would use the o-scope to ensure the shape of current waveforms matches the 3 phases of pulse charging. Secondly an ammeter will show us that our current does not exceed I_{CHRG} . Refer to equation (3). Then we would ensure the charge controller is at I_{TERM} when our battery is at peak charge voltage. This is at 2 mA.

2.2.3 Voltage Regulator

The control subsystem for our project, which includes the microcontroller and radar sensor, will primarily operate at 5V. In order to supply this voltage, a voltage regulator will be used with the 12V battery as the input. This regulator will step-down the voltage from our battery to the appropriate voltage to be used by these modules. The regulator must be compatible with the different range of output voltages that it may see from the battery.

Requirement	Verification
The voltage regulator must be able to provide 5V, +/- 5%, from a 11-16V source with a current output between 0-3 A	Perform stress testing on the voltage regulator using a DC power source in the range of 11V − 16V and with loads ranging from 0A - 3A. Use current limit on DC source for safety.
The voltage regulator must maintain thermal stability below 125°C	During stress testing, use an IR thermometer to monitor the IC temperature. Test with and without a heat sink

2.3 Power Source Selection

The power relay needs to be able to switch between the 12V DC from the rectifier and 12V DC from the battery since the battery may be below its recommended state-of-charge after a period of use. This relay will transfer to grid power in order to provide uninterrupted light to the street.

2.3.1 Power Relay

The power relay is responsible for properly and safely changing the source that the light fixture will draw power from. This relay will be a single pull double throw relay, which refers to having two inputs and one output. The relay will receive a signal from the microcontroller when it is necessary to switch the source from battery to grid power and when to return back to battery power.

Requirement	Verification
The relay must have contact switches that are rated for our maximum voltage and power from both the converter and battery sources.	The relay used for design must be rated for a maximum of 16V switching voltage and 40W
Ability to switch between sources with microcontroller signal in under 20ms	Release and operate times must be under 20ms. Turn on and turn off voltages must be between 0-5V

2.4 Intensity Control

2.4.1 Light Intensity Control

In order to properly control the intensity of the light, a minimum of 0.3 cd/m^2 must be maintained as specified by the Illinois Department of Transportation (IDOT) roadway lighting regulations [4]. Depending on the light fixture chosen, it is possible to reduce the brightness of the light upwards of 30% [6].

Requirement	Verification
The light must maintain at least 0.3 cd/m^2 (minimum legal luminance) on average during the full period of operation	Light must be able to maintain at least 0.3 cd/m^2 for 12 hours continuous (the average time from 30 minutes after sunset to 30 minutes before sunrise in Chicago during summer)
The light must be capable of adjusting the intensity based on detection of an oncoming vehicle and return to baseline intensity after the vehicle has passed.	Light must be able to reach peak intensity from its base intensity after a vehicle is detected, and return to its base intensity when no vehicle is detected. Intensity will be measured using a lux meter.

2.4.2 Radar Sensor

The radar sensor is the detection method for intensity control, it must be able to communicate with the microprocessor which handles the direct adjustment of the light fixture brightness.

Requirement	Verification
The radar sensor must be able to detect an oncoming motor vehicle at a maximum of 30 meters away, traveling at a maximum of 40 miles per hour on a United States standard 12-foot residential roadway lane with a positive detection rate of 95%.	The signal received by the sensor must be decipherable and reportable in a consistent manner that represents positive detection of a vehicle as described by the requirement.

2.4.3 Light Fixture

The light fixture is the manifestation of the power generation and control processing that makes up the bulk of our project. For this reason, it will be simpler to use an off-the-shelf light fixture to reduce development time considerably. The light will be raised to a height that allows us to simulate it functioning as a normal outdoor streetlight. A top view of light fixture/sensor placement can be shown in Figure 6. A sketch can be seen in Figure 7.

Requirement	Verification
The light fixture must be rated for at least the power output that is driven by our battery or grid connection.	The rating of the light fixture must be at minimum 40W, 12V.
The light fixture must be able to maintain at least the minimum required brightness while also having the capability of adjusting brightness to below maximum.	The light must maintain at least 0.3 cd/m^2 average luminance during operation and be able to reduce its intensity to its base value during no detection

2.5 Schematics

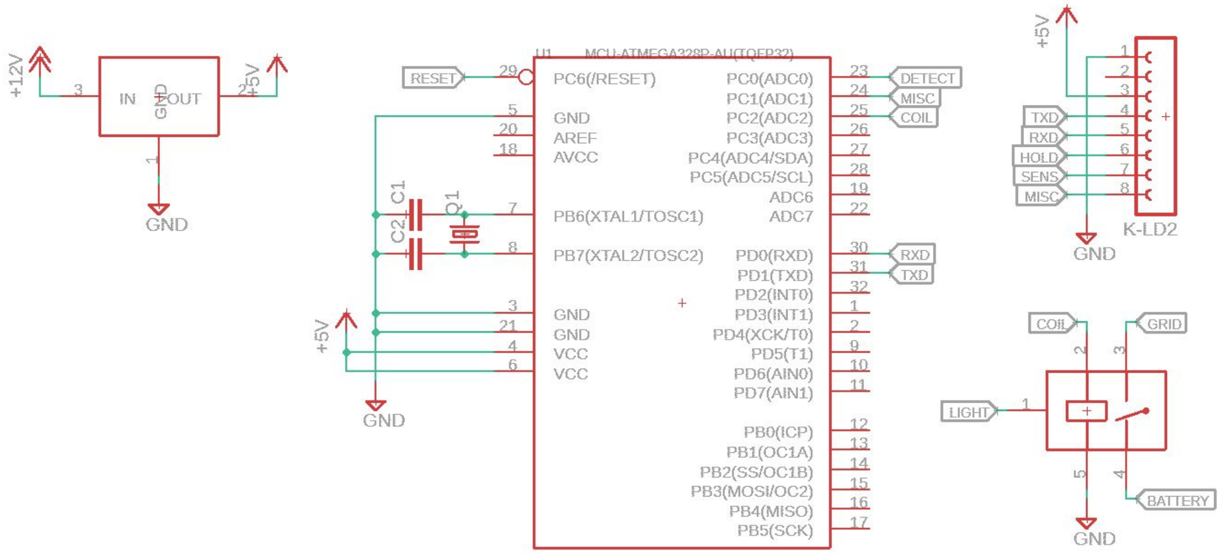

Figure 4: Control Subsystem Schematic

2.6 Tolerance Analysis

The detection aspect of our project is subject to the greatest extent of scrutiny because the primary motivation for this project is to reduce the amount of time that a streetlight is on at full intensity during the night in order to save on energy costs which are charged to taxpayers. The radar sensor that has been chosen for this project is the K-LD2 radar transceiver developed by RFbeam Microwave GmbH [11]. With factory settings, this 24 GHz radar can detect humans up to a distance of 15m and cars up to a distance of 30m. In Figure 5, the pin configuration of the K-LD2 can be seen; the Detect Out pin provides a simple output based on the module's detection algorithm but the parameters of this algorithm can be adjusted as necessary. This functionality allows for a more robust debugging process in the case that the factory settings do not work for our application. In terms of tolerance analysis, the most important parameters that will be discussed in regards to this radar module are:

1. Positive detection rate for vehicles and humans (if these values are different) at the specified distance of 30m for vehicles and 15m for pedestrians.
2. Detection reaction time/delay and its implications on proper intensity control for approaching vehicles traveling at a maximum of 40 MPH at a distance of 30m away.

Pin No.	Name	Description
1	GND	Ground pin
2	Detect Out	Digital detection output. Signals a valid detection. Low → no detection High → valid detection
3	VCC	Power supply pin (3.2 to 5.5V)
4	RX	Serial interface RX input
5	TX	Serial interface TX output
6	Hold Time In	Analogue hold time input. Range from 0 to 3V 0V → minimum hold time 3V → maximum hold time
7	Sensitivity In	Analogue sensitivity input. Range from 0 to 3V 0 V → minimum sensitivity 3V → maximum sensitivity
8	Misc. Out	Digital miscellaneous output. The function is programmable over the command set with the parameter S06. In the factory setting this output signals the direction of a valid detection. Low → backward/receding movement High → forward/approaching movement This output is only valid together with a high on pin 2 (valid detection) except if it is configured as micro detection output.

Figure 5: K-LD2 Radar Transceiver Pin Configuration

Detection rate in our application will be defined as:

$$\frac{\#\ of\ Vehicle/Pedestrian\ Correct\ Detections}{\#\ of\ Vehicle/Pedestrian\ Detect\ Opportunities} \quad (4)$$

Since our project will not be placed directly on a residential street due to local, state, and national regulations, the number of opportunities that the radar sensor will have to detect a vehicle or a pedestrian will be determined through our isolated test away from normal traffic. Considering the safety and ethics of our project, the detection rate must be at a maximum to protect drivers and other roadway users. With this in mind, the Traffic Detector Handbook from the U.S. Department of Transportation states that a strong metric for cellphone (and therefore, driver) detection stems from a Federal Communications Commission (FCC) automatic location identification (ALI) directive that requires a 67% detection rate within a distance of 50m [12]. For our application, we will use this percentage as a baseline with the goal of going above 80%. Since the specifications for the K-LD2 sensor do not include a detection rate, our tests will determine the accuracy of the module at the rated distance for detection.

In terms of detection time, the limiting factor is the delay from the radar module since the majority of the signal processing is done within this module. If there was absolutely no delay between the initial detection and the intensity of the light increasing, the available period of time before the vehicle reaches the point of the light is 1.678 seconds as seen in Equation 4. In the K-LD2 datasheet, it is stated that the reaction time of the sensor is approximately 800ms, which is 47.67% of the time before the vehicle reaches the light. During the 800ms, the vehicle traveling at 40 MPH has covered a distance of 46.93 ft. If the intensity of the light is increased at this point, there are 51.5 ft of distance remaining between the vehicle and the light. With this in mind, it must be determined whether or not this distance is adequate for the increase in light to make a difference in the overall roadway visibility for the driver, which can be confirmed during testing later on.

$$Time = \frac{hour}{40\,miles} \text{ x } \frac{mile}{5280\,ft} \text{ x } 98.425\,ft \text{ x } \frac{3600\,sec}{hour} = 1.678\,sec \quad (5)$$

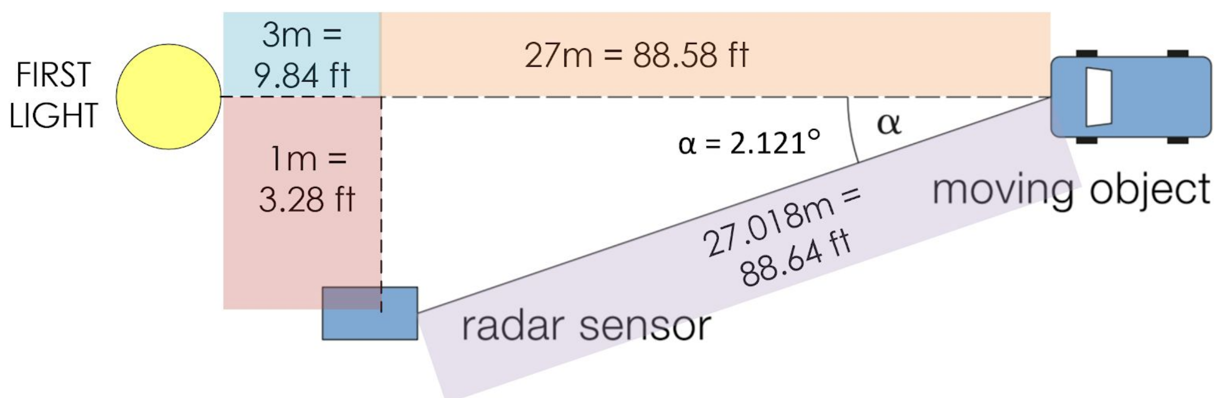

Figure 6: Radar Sensor Placement

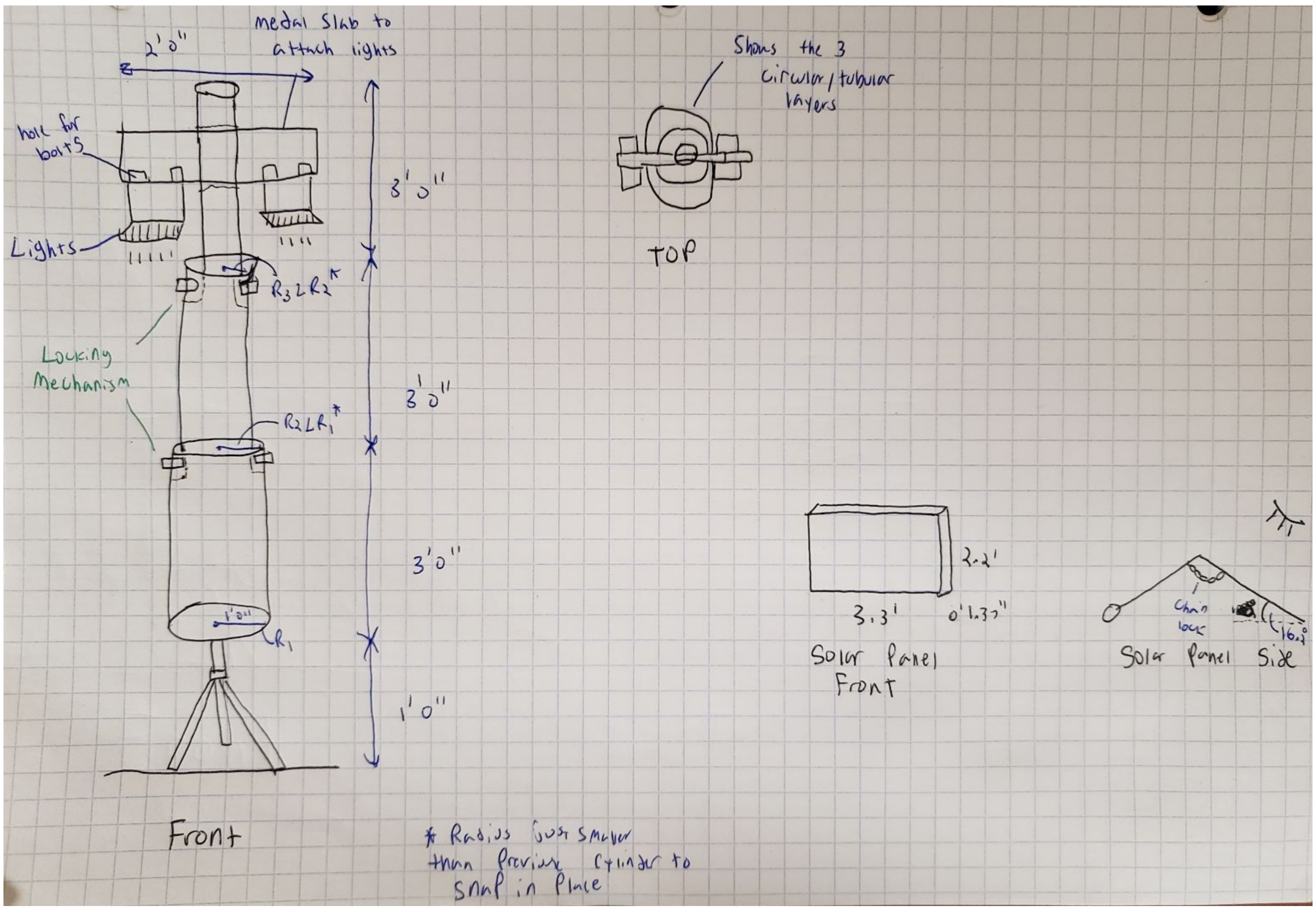

Figure 7: Sketch of Light Fixture and Solar Panel

3 Cost and Schedule

3.1 Cost Analysis

Part	Cost (prototype)	Cost (bulk)
Solar Panels: RNG-100P 100W, 12V solar panel	$125	$100
Battery: BC35-12, 12V, 100Ah flooded lead acid	$300	$200
Charge Control: BQ24650 MPPT Charge Controller	$5.52	$4.07
AC-DC Converter: LS50-12	$22.94	$22.94
Voltage Regulator: LM1084IT-5.0/NOPB-ND	$2.60	$1.28

PCBs: PCBWay (class bulk order)	$6.20	$0.20
Microcontroller: ATmega328	$1.96	$1.63
Radar Sensor: K-LD2-RFB-00H-02	$53.04	$36.17
Power Relay: G5LE-14 DC5	$1.44	$1.08
Light Fixture: Coolkun-copp1 (20W) (Amazon)	$25	$25
Power MOSFET: SI1442DH-T1-GE3CT-ND	$0.58	$0.27
Crystal: CTX1084-ND	$0.39	$0.27
Passives	$2.00	$2.00
Total	**$546.67**	**$394.91**

3.2 Schedule

Week	Brian	Josh	Corey
2/17-2/23	Retrieve Solar Panel and Battery (STL trip), visit machine shop with panels for mounting apparatus	Finalize radar sensor part number and cost, prepare schematics and board layout for radar and microcontroller, finalize light fixture part number	Retrieve Solar Panels and Battery (STL trip), Order TI-chip for battery charging module
2/24-3/2	Test panel output during different parts of the day, check batteries for state-of-charge (SoC)	Place order for Rev. 1 PCBs, radar module, microcontroller, relays, lighting fixture	Test panel output during different parts of the day, check batteries for state-of-charge (SoC)
3/3-3/9	Complete Teamwork Evaluation Begin wiring of panel and battery for data collection	Complete Teamwork Evaluation Perform Receive and begin testing of radar detection	Complete Teamwork Evaluation Collect and record panel and battery power data for different conditions (angles and

			exposure)
3/10-3/16	Begin individual progress report Wiring of panel and battery data collection continued	Complete Rev. 2 PCB for first-round PCBway orders Begin individual progress report	Begin power relay tests for battery and grid power connections Assist with outdoor radar testing
3/17-3/23	Complete solar panel and battery module Contain module in moveable casing for easy testing with other modules	Continue radar detection testing, begin outdoor tests Finalize Rev. 3 PCB for final-round PCBway orders	Begin individual progress report Program microcontroller to dim lighting fixture
3/24-3/30	Continue radar testing and reliability with new PCBs	Test power relay with battery and AC-DC converter	Test AC-DC converter for grid backup Implement into power source module
3/31-4/6	Power module testing and complete build	Radar and control module testing and complete build	Complete full structural build and implement each module
4/6-4/13	Field testing and final adjustments Final design changes	Field testing and final adjustments Final design changes	Field testing and final adjustments Final design changes
4/14-4/20	Perform and film demonstration videos Adjust modules as needed	Set up modules for functional demonstrations	Assist with filming of demonstrations and adjusting modules
4/21-4/27	Continue with demonstration videos for presentation Begin final presentation	Continue with demonstration for video Begin final report document	Edit demonstration videos Begin poster for poster session at ECEB
4/28-5/4	Complete final presentation	Complete final report document	Complete poster session in ECEB

4 Safety and Ethics

Whenever power electronics are being built, safety has to constantly be the number one thought on our minds. To prevent us from dealing with very high voltages we are ensuring our voltage never reaches above 12/24V, compared to dealing with grid voltage. However we are powering a light of 40W, therefore currents will be at high enough levels that can kill. This means at all times we need to avoid being in direct contact with live conductors. Another safety concern we need to take is double checking our circuit before ever having it be live. This will prevent careless connections, accidental shorts, or loose wires.

We will also be dealing with lead acid batteries that can be dangerous when used improperly. These batteries when fully charged and combined with high heats can cause stress on individual battery cells. Constant stress can lead to battery damage or in the worst case an explosion or fire. Battery stress can also cause the batteries to charge or discharge at a faster speed, which can result in overcharging batteries. To avoid putting high stress levels on our batteries, a charge regulator will be used to monitor the state of the battery and prevent situations of overcharging or undercharging of our batteries.

For testing our design, we will be using vehicles of different sizes to ensure our sensors functionality. These tests will will be performed in a safe environment with extreme caution to our surroundings, other cars, and the safety of the driver. Getting hit by a car would lead to severe injury. When using the radar sensor we must make sure there is no chance of getting in the cars way.

In terms of ethics, we must remember during this project that #1 "To hold paramount the safety.."[9] is our top ethical dilemma. Street lights are used for public safety at night. We can not cut corners or risk there being no light. That is why regardless of our energy storage and doppler radar, we will be hooked up to the grid and ready to output full power and light intensity if anything goes wrong. Also since we will be dealing with the aspect of saving money, principle #2 would be a dilemma. It states "to avoid real or perceived conflicts of interest whenever possible…", and we'd know how much money a town is saving on their bill. Many parties could be interested in our data and we'd need to maintain our ethics and not give away data that should not be given away.

5 Citations

[1] C. Landau, “Optimum Tilt of Solar Panels,” Optimum Tilt of Solar Panels, 2017. [Online]. Available: https://www.solarpaneltilt.com/. [Accessed: 07-Feb-2019].

[2] “The Light Post,” *Office of Energy Efficiency & Renewable Energy*, May-2012. [Online]. Available: https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/msslc_enews_may2012.pdf. [Accessed: 07-Feb-2019].

[3] R. Gray, “Future - The biggest energy challenges facing humanity,” *BBC News*, 13-Mar-2017. [Online]. Available: http://www.bbc.com/future/story/20170313-the-biggest-energy-challenges-facing-humanity. [Accessed: 07-Feb-2019].

[4] “Highway Lighting,” *Illinois Department of Transportation*, May-2015. [Online]. Available: http://www.idot.illinois.gov/assets/uploads/files/doing-business/manuals-split/design-and-environment/bde-manual/chapter 56 highway lighting.pdf. [Accessed: 07-Feb-2019].

[5] “Dimming of LED Street Lighting,” *Northcliffe*. [Online]. Available: http://northcliffe.org/DIMMING_OF_LED_STREET_LIGHTING. [Accessed: 07-Feb-2019].

[6] “The Future of Roadway Lighting,” *U.S. Department of Transportation/Federal Highway Administration*, 2015. [Online]. Available: https://www.fhwa.dot.gov/publications/publicroads/15novdec/06.cfm. [Accessed: 07-Feb-2019].

[7] B. Spiller, “All Electricity is Not Priced Equally: Time-Variant Pricing 101,” *Environmental Defense Fund*, 21-Dec-2015. [Online]. Available: http://blogs.edf.org/energyexchange/2015/01/27/all-electricity-is-not-priced-equally-time-variant-pricing-101/. [Accessed: 08-Feb-2019].

[8] “What is a Solar Charge Controller,” *altEstore.com*. [Online]. Available: https://www.altestore.com/store/info/solar-charge-controller/. [Accessed: 08-Feb-2019].

[9] “IEEE Code of Ethics,” *IEEE - Advancing Technology for Humanity*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 08-Feb-2019].

[10] L. Doman, “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis,” *Factors Affecting Gasoline Prices - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration*, 14-Sep-2017. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=32912. [Accessed: 18-Feb-2019].

[11] “K-LD2 Datasheet.” RFbeam Microwave GmbH, St. Gallen, Switzerland, Sep-2018.

[12] “Chapter 1, Traffic Detector Handbook: Third Edition-Volume I,” *U.S. Department of Transportation/Federal Highway Administration*, May-2006. [Online]. Available: https://www.fhwa.dot.gov/publications/research/operations/its/06108/01.cfm. [Accessed: 21-Feb-2019].

[13] “What Is A Charge Controller?,” *Wholesale Solar Blog*. [Online]. Available: https://www.wholesalesolar.com/solar-information/charge-controller-article. [Accessed: 22-Feb-2019].

[14] “Battery Maintenance | Trojan Battery Company,” *Trojan Battery Company*. [Online]. Available: https://www.trojanbattery.com/tech-support/battery-maintenance/. [Accessed: 22-Feb-2019].

[15] “Lead Acid Battery Charging Basics and Chargers,” *Lead Acid Battery Charging Basics and Chargers*, 17-Nov-2017. [Online]. Available: https://www.powerstream.com/SLA.html. [Accessed: 22-Feb-2019]

[16] Falin, J., Mauney, C. and Nortman, S. (2011). Using the bq24650 to Charge a Sealed, Lead-Acid Battery. 1st ed. [ebook] Texas Instruments, p.6. Available at: http://www.ti.com/product/BQ24650/technicaldocuments [Accessed 22 Feb. 2019].