Electrical Engineering Senior Project Report

Student Experimental Farm Smart Pathway Lighting System

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Abstract

This project works together with the Student Experimental Farm (SEF) and the DC House in order to install a smart lighting pathway system. This system will run off of DC power supplied by the solar panels connected to the DC House. This project tested and explored the group's abilities to design and implement a full system run off of 48V DC. By installing this system it will greatly improve the ease for students to work at the SEF beyond daylight hours. The system will allow continuous dull lighting and will switch to full brightness once a person is detected. This feature goes along with the ideals of the DC House, saving energy. This project helped to show the capabilities of a DC system and can impact the lives of those in communities with no access to an AC grid. The results of this system were not as successful as planned. The wiring within the junction boxes proved to be quite tricky so the system does not work at its full potential, however this does lead to further improvements by students to come.

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Chapter 1. Introduction

In today's world, electricity has become a great part of many lives here in the United States and all over the globe. Unfortunately, electricity has become so high in demand that alternative sources of energy, which are not always very efficient, have been necessary to implement. The National Action Plan for Energy Efficiency, initiated in December 2005, aims to achieve all cost-effective energy efficiency in the Unites States by the year 2025. The National Action Plan for Energy Efficiency serves as a framework to assist with the development and implementation of energy efficient policies in natural gas and electricity supply and delivery[1]. With the ultimate goal to reduce energy costs in homes, buildings, and industries, the action plan outlines ten detailed goals for implementation. The goals fall under different categories such as energy efficiency potential studies for establishing cost effectiveness tests, developing policies to ensure robust energy efficiency practices, and implementing advanced technologies [1].

One solution to this energy efficiency issue is to have power generated locally and directly routed to the desired area. This is being done with the DC (Direct Current) House at Cal Poly State University in San Luis Obispo. This DC House project was intended to provide a system run fully off of direct current electricity while also utilizing renewable power sources and human-powered generators [2]. This structure benefits those in rural or secluded areas who have no access to an AC grid and also will promote the use of alternative power sources.

The DC House is an example to demonstrate very important aspect of encouraging a cost-efficient energy solution. As it is seen from the name, the DC House uses only Direct Current to provide energy for all components that encompass the house. The main form of renewable energy used to power the house are solar panels. Solar panels produce DC power,

which in urban areas require an inverter to convert the DC power to AC power. This inverter creates a power loss that is undesirable due to the larger cost to operate. Therefore, for this system where there is a large use of solar panels it is more efficient to eliminate the need for inverters, to convert to AC, and use the DC power.

The DC House and the National Action Plan for Energy Efficiency both provide encouragement that a more energy efficient world is upon us. The National Action Plan for Energy Efficiency will show great improvement in regards to cost and energy efficiency in the United States over the next several years while the DC House will benefit those in rural or secluded areas with no access to a grid to gain electricity. While utilizing the solar panels available at the DC House we can provide straight DC power without the need for an inverter, thus eliminating the associated power loss. With both of these two projects, there will be a positive impact on energy efficiency globally.

One common electrical load that can help in improving efficiency in energy use is lighting. At present, the majority of lighting systems installed makes use of AC power. This includes systems that directly run off of renewable energy sources such as solar panels, which inherently output DC power. As stated earlier, this switch from DC to AC requires the use of an inverter and results in power losses, which in turn decreases the efficiency of the system. Being able to power light bulbs directly through DC power would be the most efficient use of energy. This process is possible today due to advances in technologies such as DC-DC converters and LED light bulbs operating directly from DC input voltages.

The integration of advanced technologies plays an important role in achieving energy efficiency in both natural gas services and electricity services. Today's lighting systems can also take advantage of a variety of technologies in order to become more energy efficient. These technologies include microcontrollers, motion sensors, and communication devices. With such

technologies, it is now possible to operate lighting in ways that are not possible in the past. Lighting may now be adapted to the surrounding ambient conditions, presence of a user, colors that affect user's comfort, etc. This leads to the development of what many people refer to as "Smart Lighting" which aims to not only reduce cost associated energy usage, but also convenience and comfort for the users.

Chapter 2. Background

The Student Experimental Farm (SEF) at Cal Poly San Luis Obispo serves as a learning community where students can learn from and experiment with different project ideas. Since 1989, the two-acre farm has been the home to a range of projects related to alternative agriculture, gardening, sustainability, and energy. In addition, the SEF is also used for teaching purposes and serves as a classroom for classes such as the appropriate technology and energy class and Religion and Wine class. As of today, there is nine ongoing projects at the SEF. Projects related to gardening consists of two private gardens, Agroecology Club's garden, Cal Poly's Aquaponics, the polyculture nursery focused on sustainable nursery crop productions, and the mushroom lab focused on growing gourmet and medicinal mushrooms. Projects related to renewable energy sources include the DC house which runs directly off of PV system power, the solar concentrator kitchen project is focused on building a solar kitchen for developing countries and the solar ice project is focused on using PV energy to power an ice-making apparatus to be used to benefit developing communities. Most of the renewable energy projects at the SEF harvest energy in order to deliver power for a purpose whether it is to power an ice-making apparatus or a solar kitchen. The DC House, on the other hand, serves to do more than utilizing solar power. It is a research effort that focuses on the development of a purely DC electrical system whose energy source come mainly from renewable energy sources, though having a mixed energy of energy sources which includes the utility grid is also feasible.

The DC House started in 2010 with the aims to improve access to electricity in rural areas but mainly in developing countries. The DC House is designed to be able accept multiple energy sources at low power level and to distribute the power to a house using DC electricity. Recently, the DC House has expanded to energy efficiency research whose goal is to reduce the energy cost by having a DC power distribution inside a residential home. To date there are a

total of three DC House prototypes that have been completed to demonstrate and show case the DC House technology: at Cal Poly State University, at Technological Institute of the Philippines, and at Universitas Padjadjaran Indonesia. At Cal Poly, the prototype is located at the Student Experimental Farm (SEF) and the DC House project can now serve to support energy demand and facilitate activities at the SEF.

Currently, the activities at SEF is limited to the hours where sunlight is available. With sunlight as the only form of lighting, students cannot work on their projects and classes cannot take place past sunset. The implementation of a pathway lighting system at the SEF will allow access to SEF after sunset and facilitate more activities to take place throughout the day. The goal of this project is therefore to design and install a pathway DC lighting system at SEF which will be powered by the DC House. The pathway will mainly be placed to set a path leading directly to the DC House. To reduce the energy used the DC lighting system will utilize LED light bulbs and will incorporate smart dimming and “following” features. The “following” feature uses motion sensors in conjunction with microprocessor to power lights five feet ahead and behind the person at all times; thus, the lights follow the person walking on the pathway.

Chapter 3. Design Requirements

In order to begin the design for the lighted pathway, block diagrams were drawn up to get a basic understanding of the necessary components required for this system. Shown in Figure 3-1 is the level 0 block diagram for the pathway lighting system. This diagram illustrates the two inputs, sunlight and motion, while outputting a lit LED.

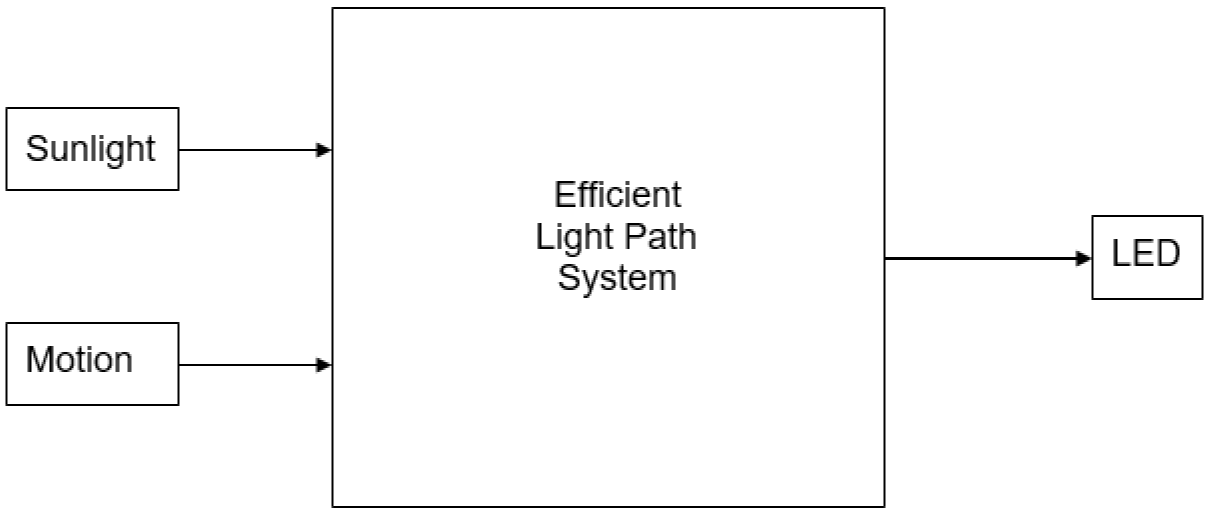

Figure 3-1: Level 0 Block Diagram

Table 3-1 shows more details about the functionalities of the inputs, outputs, and the efficient light path system black box.

Table 3-1: Level 0 — Efficient Light Path System

Black Box Module	Efficient Light Path System
Inputs	Sunlight and motion detected by a person walking past the system
Output	LED
Functionality	The LED will be lit up as long as motion is detected along the pathway along with the absence of sunlight.

Figure 3-2 shows the level 1 block diagram for the pathway lighting system. This diagram displays a more detailed approach to the system design. The two inputs are shown as before. First the sunlight enters the module and is detected by the ambient light sensors to determine if it is dark enough to turn on the LED’s if motion is detected. Motion is also inputted to the system, the motion sensors detect the motion. This information is then sent to the MCU with a DC/DC converter to drop the voltage from 48V to 3-5V, along with the light sensor information, and then outputted to the LED.

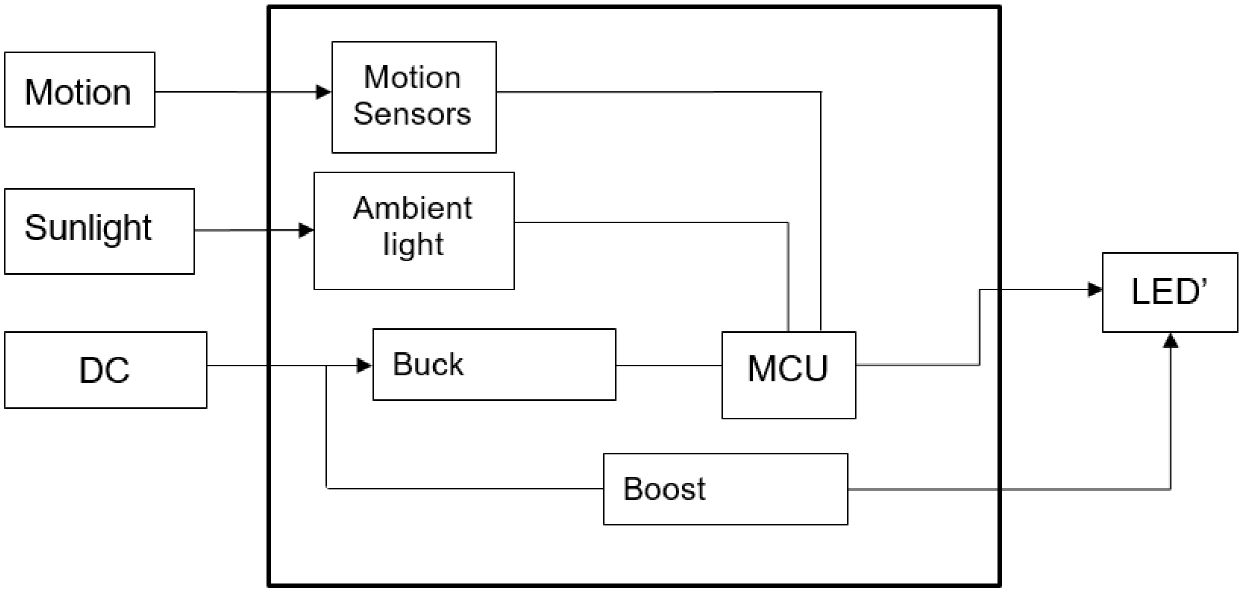

Figure 3-2: Level 1 Block Diagram

Tables 3-2 through 3-6 detail the functionalities of the pathway lighting system. As briefed previously, the level 1 diagram shows the two inputs to ambient light sensors and motion sensors, DC Voltage used to power the LED's and the MCU to determine when the LED's turn on.

Table 3-2: Level 1 — Motion Sensors

Module	Motion Sensors
Input	The heat detecting sensors detects motion within a 10 ft diameter
Output	Depending on whether there is a person nearby, the sensor will send signal to Arduino, MCU, to keep lights on or off
Functionality	The motion sensor will determine when a person is nearby so to have the lights turn on only when necessary

Table 3-3: Level 1 —Ambient Light Sensors

Module	Ambient Light Sensors
Input	Sunlight
Output	High or low signal to MCU
Functionality	The light sensor will be able to detect whether it is an appropriate time of day for the LEDs to turn on. Once they stop detecting sunlight, they send a low signal to the MCU allowing the LED to light up. This helps with energy conservation.

Table 3-4: Level 1 —Buck Converter

Module	Buck Converter
Input	48V (DC) from DC House
Output	3-5V (DC)
Functionality	The buck converter brings the voltage level down from 48V to a voltage that is safe and required by the Arduino MCU (3-5V)

Table 3-5: Level 1 —Boost Converter

Module	Boost Converter
Input	48V (DC) from DC House
Output	48V (DC)
Functionality	The boost converter's purpose is to keep the voltage at 48V throughout the system. There will be power loss along the line as the distance accrues so the boost converter will keep bumping up the voltage to 48V as needed by the LEDs.

Table 3-6: Level 1 —MCU

Module	MCU
Input	3-5V power input from buck converter. High or low signal from ambient light sensor and motion sensor
Output	High or low signal to LED
Functionality	The MCU's purpose is to gain information from the motion sensor and ambient light sensor in order to set the LEDs on or off when necessary.

The goal of this project is to provide an efficient pathway lighting system for the Student Experimental Farm (SEF). In order to accomplish this, various technical design requirements are needed as listed in Table 3-7.

Table 3-7: Technical Design Requirements

Engineering Requirement	**Justification**
The system shall run on 48V DC Power	The system will be receiving power generated from solar panels that charge a 48V battery. By not using inverters and instead using DC power directly, less power loss occurs
The system shall track movement and sunlight	In order to make sure the lights are only on when needed, the lights will only turn on when the sun goes down, and will only turn bright if someone walks close by
Wiring between LEDs shall be installed underground	Wiring underground is safer and more aesthetically pleasing
The system shall provide auxiliary power of 150 Watts to the SEF greenhouse	During power outages the SEF greenhouse will utilize this backup power to keep plants and fish alive
The system shall be protected from the environment	Since this project will be outdoors, all components and systems must be protected from environmental issues like rain or wind

Electrical Specifications:

The SEF light path system will consist of three circuits. One circuit will have 5 bulbs, one will have 11 bulbs, and the other will have 19 bulbs. Since the input power of the system is 48 Volts DC, the light bulbs are rated for input voltages of 48V DC. The light bulbs are also rated at 9 Watts each. Using the rated power and voltage of each bulb, the current needed in each circuit is estimated to be 0.1875 Amps. Using this current it is possible to determine the minimum wire gauge needed to provide the necessary voltage and current to each bulb, which was determined to be 28 gauge AWG [3]. The size of the wire gauge is important when calculating voltage drops. To account for these voltage drops, DC-DC converters will be used to

boost the voltage up to 48 Volts whenever it drops to low. The amount of converters needed will be determined after performing a cost analysis of wire size vs. number of converters needed.

In order for the bulbs to perform efficiently and communicate with each other, microcontrollers and infrared sensors will be used. Each bulb will have an infrared sensor attached to its base, which will identify human movement. Every other bulb will also have a microcontroller connected to it. Each MCU will be able to communicate with three light bulbs(the bulb it's attached to, one behind, and one in front) and will be programmed in a way that will allow the bulbs to become bright only when a person is close by and automatically dim as a person walks away. These components only require 5V input, so a DC-DC converter will be used to step down the source voltage from 48V to 5V. The amount of converters needed will be determined after performing a cost analysis of wire size vs. number of converters needed.

Mechanical Specifications:

All wiring between lights will be installed underground. In order to protect the wires, conduit will be used to house the wires. The lights will be mounted using PVC pipe to allow wiring to access the bulbs from the conduit. Hard plastic will be used for protection.

Physical Dimensions:

The light path is comprised of 3 circuits, which are labeled as Path1, Path 2, and Path 3 in **Figure 3-3**. Path 1 is 170 ft., Path 2 is 290 ft., and Path 3 is 100ft. There are 35 total bulbs: 11 for path 1, 19 for path 2 and 5 for path 3. The distance between each bulb is roughly fifteen feet. The bulbs will be installed at a height of approximately 2 feet.

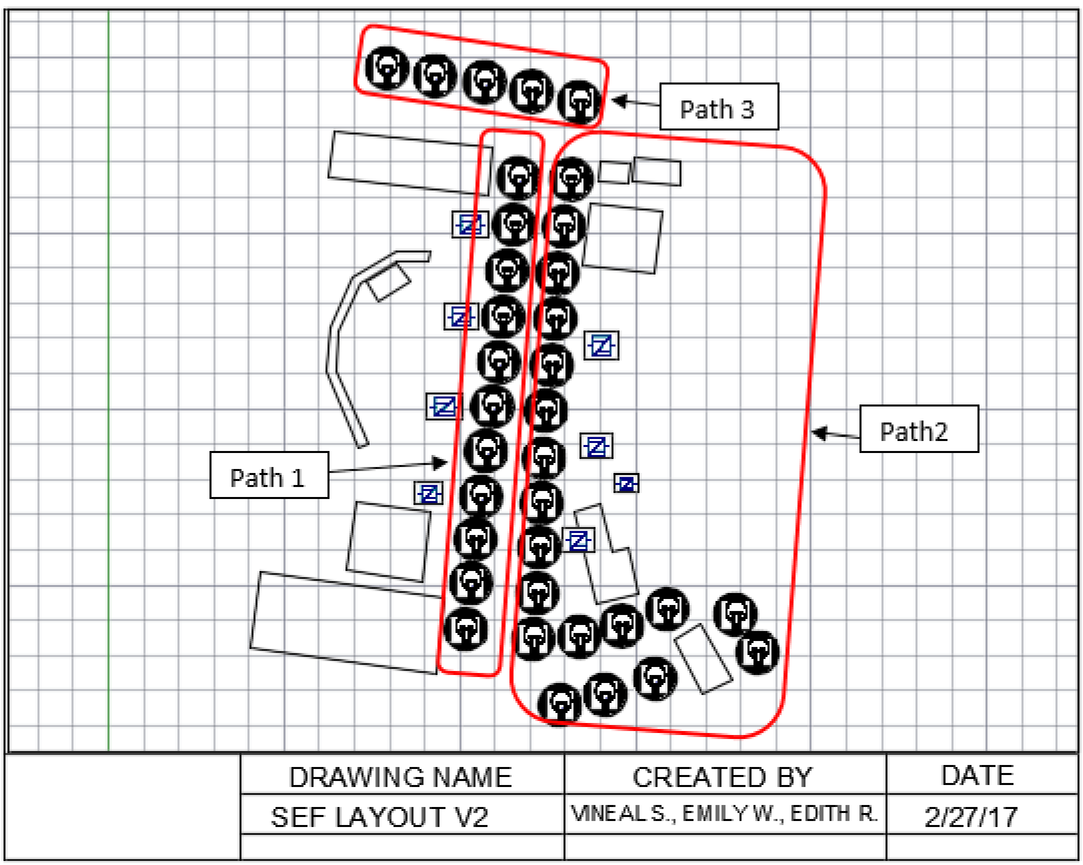

Figure 3-3: Layout of SEF Light Path

The overall system's specifications are separated into three subsystems as listed in Table 3-8. Each subsystem is a circuit controlling one of the three light paths and will operate independent from the other circuits. The important specifications per subsystem is the power consumption. The power usage for the subsystem light path one is 171.03 Watts, Subsystem Light Path two uses 99.12 Watts, subsystem Light Path three uses 45.12 Watts. The overall system power consumption is 327.15 Watts. In addition to the overall systems specifications, we listed individual component specifications as seen in Table 3-9. The individual components are the components found in each subsystem circuit. Conduit specifications can be found in Table 3-10.

Table 3-8: System Specifications Per Light Path

System Specifications Per Light Path								
	Power (W)	Supply Voltage (V DC)	Supply Current (A)	Length (ft)	LED Bulb Quantity	Motion Sensors Quantity	Ambient Light Sensor	ATMEGA 328P MCU Quantity
LightPath 1	171.03	48	3.563	290	19	19	1	12
LightPath 2	99.12	48	2.063	170	11	11	1	7
LightPath 3	45.12	48	0.938	100	5	5	1	3

Table 3-9: Component Electrical Specifications

Component Electrical Specifications						
Component	Supply Voltage (V)	Supply Current (mA)	Power Consumption (W)	Output Voltage (V)	Output Current (A)	Frequency (MHZ)
LED Light Bulb	48	NA	9	NA	0.187	NA
Motion Sensor	5 -20	65	0.325	3.3	NA	NA
ATMEGA328 P IC MCU	1.8-5.5	0.2 (at 1.8V, 1MHz)	360 uW (at 1.8V)	1.8-5.5	200 u (at 1.8V)	4-20
High Sensitive light sensor	1.5-6	1-5	0.006-0.040	NA	1u-13u	NA
DC/DC Converter	48	NA	264	48	5.5 Max	NA
Buck Converter (Light Path 1)	48	NA	17.5	5	3.5	NA
Buck Converter (Light Path 2)	48	NA	10	5	2	NA
Buck Converter (Light Path 3)	48	NA	5	5	1	NA

Table 3-10: Mechanical Specifications

Mechanical Specifications			
	Total Length (ft)	Inside Diameter (in)	Type
Conduit	600	0.0.622	Metallic

Chapter 4. Design and Simulation

The initial design of this system can be seen in Figure 3-3, which consists of three circuits, one of which (Path 1) would provide 150 Watts of additional power for the SEF greenhouse. A cost analysis was done to determine the cheapest and most effective combination of wire-gauge and DC-DC converters to transmit 48 volts DC throughout each path, which can be seen in Table 4-1. The voltage drop at the load of each path was calculated based on the following equation: V_d = 2*R*L*I1000, where R is the resistance of the wire, L is the total distance, and I is the current [4]. The current was calculated for each path by taking the total power in each path(power rating of each bulb * number of bulbs) and dividing that by the voltage of each path (48 volts). The resistance was given based on the chosen wire gauge. The total cost of the system was also estimated by accounting for all components and materials that would be needed to construct the initial design (See Table 4-2). After reviewing the total cost of the system, it was determined that the proposed design would cost too much and therefore needed to be scaled down.

Table 4-1: Original Cost Analysis of Wire Gauge vs. DC-DC Converters

	Wire Gauge	Voltage drop at load (V)	Cost of Wire (per ft)	Total Cost of Wire	Number of DC-DC Converters	Distance between converters(ft)	Voltage drop between converters(V)	Cost of converters	**Total Cost**
Light Path 1	8	1.474	0.59	259.6	0	0	0	0	259.6
	14	5.92	0.24	105.6	2	73	1.964	150	255.6
	18	15.019	0.27	118.8	4	44	3	300	418.8
(Without 150W greenhouse power)	18	5.972	0.27	118.8	2	73	1.981	150	268.8
Light Path 2	6	0.912	0.38	239.4	0	0	0	0	239.4
	16	9.346	0.36	226.8	3	72.5	2.151	225	451.8
	12	3.664	0.29	182.7	1	158	1.838	75	257.7
Light Path 3	18	1.234	0.27	64.8	0	0	0	0	64.8

Table 4-2: Original Total System Costs

	Quantity	Total Cost
Arduino Chips	25	$50
Sensors	40	$67.96
Bulbs	40	$201.65
Conduit	66	$165
Conduit fittings	35	$16.45
conduit end caps	3	$0.69
N-MOSFETS	35	$11.28
5-volt wire	14	$144.90
Wiring total from cost analysis	-	$578.10
TOTAL COST		$1,236.03

The design of this system was modified in order to keep within the budget. By reducing the number of pathways, money will be saved by reducing the amount of construction materials (wire, conduit, etc.) and components (sensors, MCUs, light bulbs, MOSFETs) needed. Initially, as seen previously in Figure 3-3 the system was to have three different pathways with a total of 35 bulbs. After the system modification, it is left with only one path, path #2. Path #2 was chosen as the pathway to keep due to the centralized location of the pathway as well as keeping in the budget. The new layout for the current design can be seen in Figure 4-1.That pathway was originally designed to have 19 bulbs, post modification the pathway was decreased to 17 bulbs in order to keep wiring and conduit layout simplified. This new system design includes 1 DC-DC converter as opposed to 8 converters in the previous design. The plan to install 150 Watts of power for the SEF greenhouse was also cut as it was designed to be part of path 1, which will no longer be constructed. Again, all of these modifications have been done in order to lower the total cost of the project. The updated cost-benefit analysis can be seen in

Table 4-3 and the updated total system cost breakdown can be seen in Table 4-4.

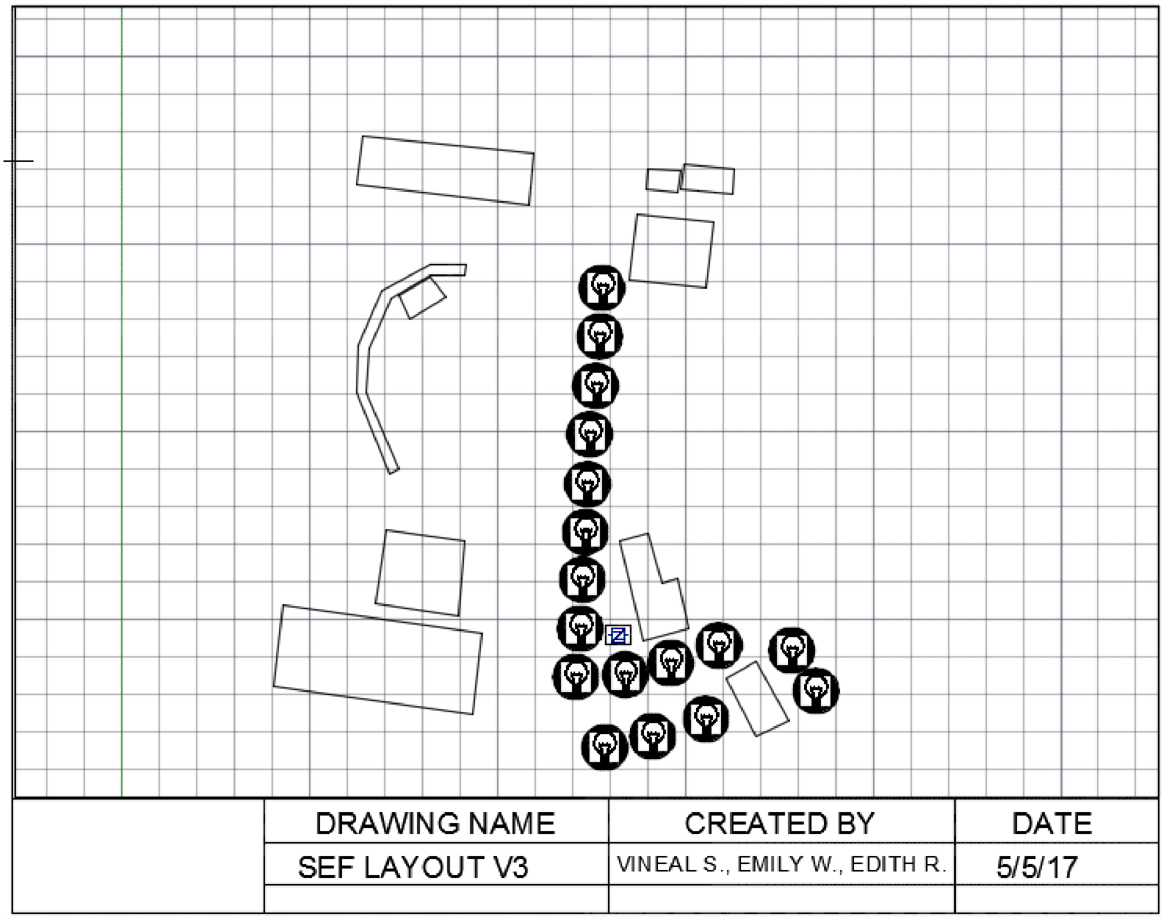

Figure 4-1: Updated Layout of SEF Light Path

Table 4-3: Updated Cost Analysis of Wire Gauge vs. DC-DC Converters

	Wire Gauge	Voltage drop at load (V)	Cost of Wire (per ft)	Total Cost of Wire	Number of DC-DC Converters	Distance between converters(ft)	Voltage drop between converters(V)	Cost of converters	**Total Cost**
Light Path 2	6	0.912	0.38	239.4	0	0	0	0	239.4
	16	9.346	0.36	226.8	3	72.5	2.151	225	451.8
	12	3.664	0.29	182.7	1	158	1.838	75	257.7

Table 4-4: Updated Total System Costs

	Quantity	Total Cost
Arduino Chips	25	$50
Sensors	40	67.96
Bulbs	40	$201.65
Conduit	32	$80
Conduit Fittings	17	$7.99
Conduit Elbow	3	$1.00
Conduit End Caps	1	$0.23
N-MOSFETS	20	$7.64
5-volt wire	8	$82.80
Wiring total from cost analysis		$257.70
TOTAL COST		$756.97

A block diagram of the updated system can be seen in Figure 4-2.

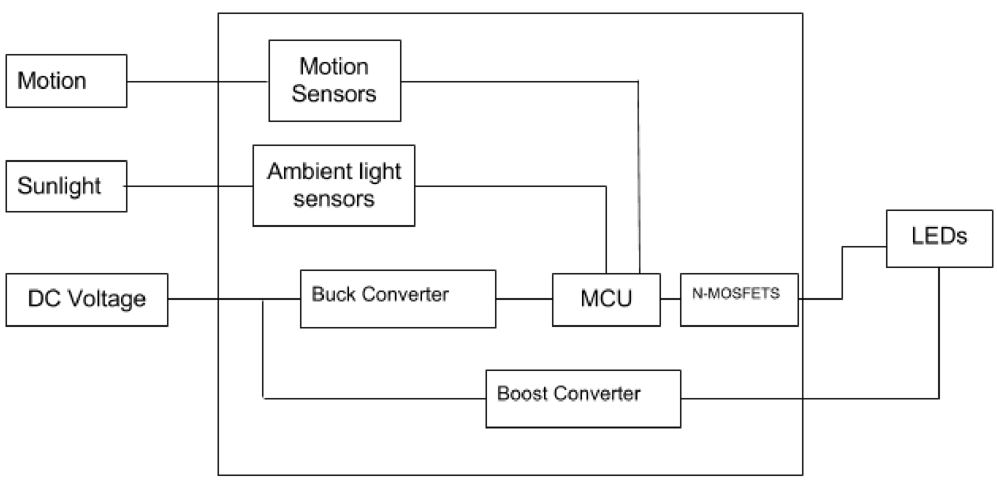

Figure 4-2: System Design Block Diagram

Chapter 5. Hardware Test and Results

The hardware portion of this project was very time consuming and laborious. The first step in this process was to dig the trenches that the conduit would be laid into. To stay up to the NEC code regulations, the trench must be 18 inches deep. Because of the time commitment required to dig the trenches, it was decided to eliminate another portion of the pathway in order to finish the project on time. The new, and final, diagram of the pathway layout can be seen in Figure 5-1. With this new layout, there are still 12 bulbs installed from the entrance of the SEF to the DC House. Along with the 12 bulbs there will be one 48-48V DC/DC converter and one 48V-5V DC/DC converter. These are also shown in Figure 5-1. Once the trenches were dug and the conduit was laid, the 14 gauge wires were ready to be pulled along the pathway through the conduit all connected by junction boxes every 10 ft. At these junction boxes are where each light bulb is installed. Please see Figure 5-2 for a visual representation of the junction box housing for the light bulb circuitry.

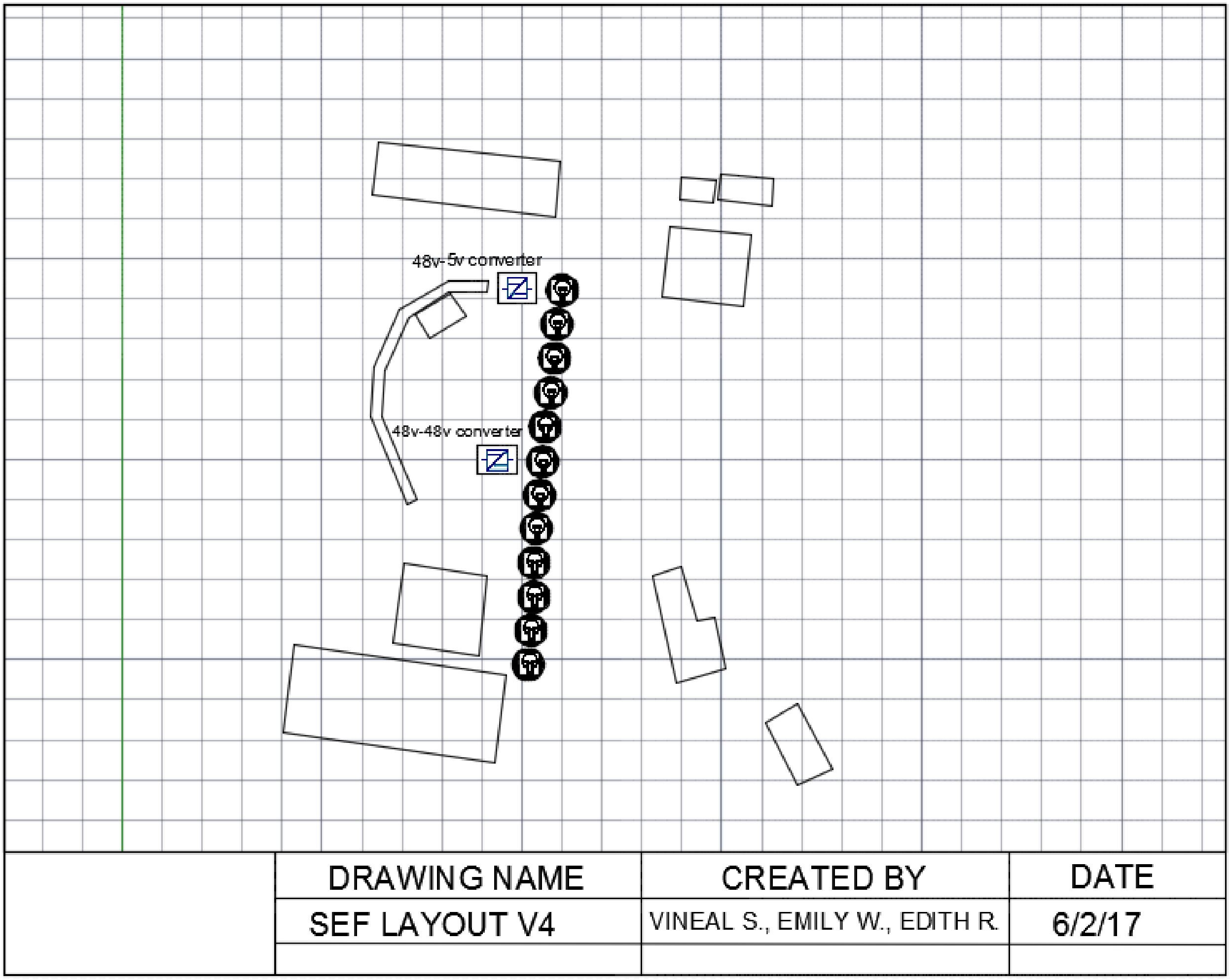

Figure 5-1: Final Design of SEF Light Path

Figure 5-2: Junction box to house circuitry

While getting the pathway ready at the SEF, the circuit boards were also built. By soldering on the components (PIR sensor, Arduino Uno, and NMOSFET) durable connections were made to ensure that the boards will be able to withstand any wear felt from the outdoor elements. The continuity test was performed during soldering to check for any shorts between pins. To test the circuits 48V was needed in order to power the system as well as 5V to power the Arduino chip. The Rigol DP832 Power Supply was utilized in order to meet these requirements with a current limit set to 3 amps. A block diagram of this test setup can be seen in Figure 5-3. The Rigol DP832 power supply was able to provide both Vcc (5 volts) and Vdd (48 volts) simultaneously to the circuit. In lab testing involved building the circuit in Figure 5-3 on a

breadboard first, to validate the Arduino code's ability to control the circuit given sensor readings as inputs. Next, we tested the actual boards to ensure that all of the components were working together correctly. By setting up the PIR sensors in different directions and then moving ourselves in front of them, we were able to see if the corresponding lights bulbs lit up at the correct times.

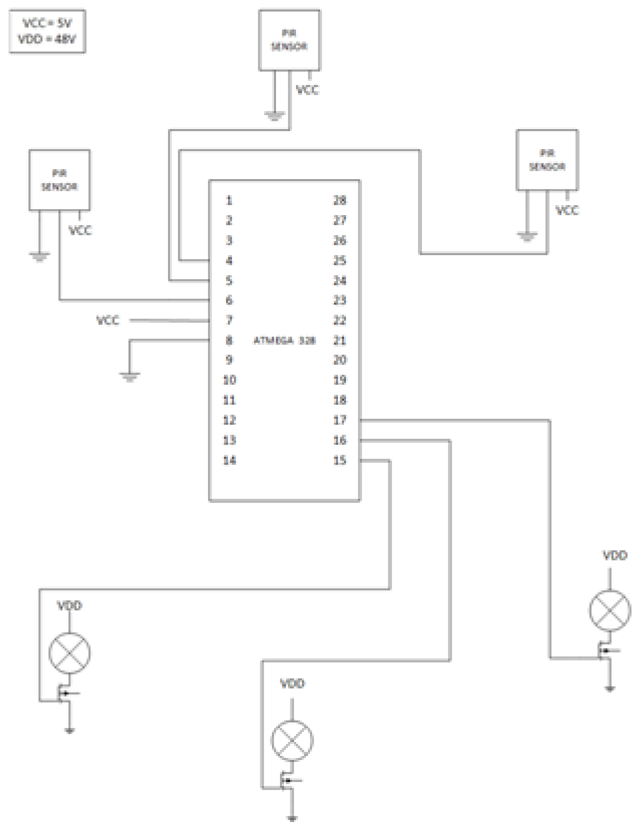

Figure 5-3:Circuit used for testing

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Figure 5-4: SEF Light Path

Figure 5-4 shows the light pathway leading up to the DC house.The trenches will be covered up with dirt once the system functionality has been achieved. The lightbulb housing has not been installed at the time of this picture due to testing purposes.

On-site testing was necessary once all of the wiring was completed and all components were intact. A Rigol DP832 power supply was brought to the site to supply power due to the current inability to directly connect the system to the DC House via MISO. This power supply was able to be connected to both the 48V and 5V lines and supply the proper amount of

voltage, respectively. Power was shown to have been directly distributed throughout the line of all 12 bulbs by the display of all bulbs turning on at some point. From this it was easy to see that power was not an issue. However, the bulbs were not showing correct function by only staying on or off permanently during each trial run. The initial troubleshooting method was to verify that there were not any incorrect or mixed up wire connections between all wires. When all issues were resolved with any mixed up wire connections, the next troubleshooting step was to go to each junction box, specifically of those bulbs that were not functioning correctly, and checking the wire connections within the wire nuts. By pulling on each wire tied together by the wire nut, it was determined if there was a poor connection that could be fixed by tightening the nut and verifying all wires were touching and a solid connection was made. This was the toughest portion of all the troubleshooting as there are so many different wires and possible connections that could get loose at any moment. Once confidence was set in the wire connections, a multimeter was utilized to verify the voltages at each node. The microcontroller was intended to output 5V to each MOSFET and sensor and these voltages ended up checking out at the correct times. It was decided to work on the system at smaller chunks at a time by disconnecting seven of the far lights and keeping the first five lights connected to the power supply. By doing this we were able to hone in on the issues with the system with much more ease and confidence. The lights were working as intended with the exception of the middle bulb which was set on the entire time. Unfortunately, the team was unable to diagnose the exact problem that this light was having. After switching out all components, redoing the wiring and verifying the correct voltages being sent to the components, it was determined that there must be some issues within the wiring somewhere that we were unable to find. With this first section unable to function properly, it is not likely that the rest of the system will function correctly either. A change in the arduino code will be made to allow all lights to be turned on to a very dim setting at all times when powered on, and if an individual is sensed by the junction box the lights

will change to a much brighter setting. This will allow light to always be accessible during nighttime hours despite the potential lacking of the full intended function of the smart lighting.

Chapter 6. Conclusion and Further Improvements

The Student Experimental Farm is a great resource for students of all majors and can now be more accessible during nighttime hours. The purpose of this project was to provide a way for students to safely and easily traverse from one side of the SEF to the other at night. This project was also an extension of the DC house project and attempted to test the usefulness of using DC bulbs for outdoor lighting. This project proved that using DC light bulbs is effective and can be implemented for off-grid purposes when wired correctly. The addition of smart lighting through the use of micro-controllers and motion sensors definitely added complexity to the design. After testing in lab it was determined that the design worked as expected, but implementing it at the farm proved to be much more difficult and time consuming.

The unexpected length of time it took to physically dig the trench and wire components prevented us from having enough time to find the wiring issue at the SEF. The system that we tested in lab worked as expected, however we were only able to test three bulbs at a time due to limited space and wires in the lab room. Connecting the whole system of 12 bulbs together caused issues that we did not see when testing three at a time in lab. One improvement that could be made would be to increase the size of the junction boxes used to house the components. The junction boxes are removable, so if someone were to purchase larger boxes and drill holes for the wires to enter, connecting wires using wing connectors would become easier. This would help to prevent any loose wiring connections, which were sometimes found during troubleshooting. The PIR sensors worked as expected, but they were not the most responsive. Better PIR sensors would result in a more responsive system.

Because the system was not able to work using a power supply that provided the necessary 48 volts and 5 volts, the 48-5 volt converter was not installed into the system. Calibration and soldering of leads to the converter was performed in lab, so it has been proven

to work correctly. Due to the lack of time and inability to find the wiring problem it was not connected to the system, but can easily be installed once the main problem is solved.

The unexpected length of time used to dig the trench for the path as well as connecting wires prevented us from having enough time to troubleshoot the light path. Successful testing in lab proves that we are on the right track, but currently the system at the SEF is not performing as it was designed to.

References:

[1]. "National Action Plan for Energy Efficiency Vision for 2025: A Framework for Change", *United States Environmental Protection Agency*, 2017. [Online]. Available: https://www.epa.gov/sites/production/files/2015-08/documents/vision.pdf [Accessed: 1- Feb- 2017].

[2]. "The DC House Project", *Calpoly.edu*, 2017. [Online]. Available: http://www.calpoly.edu/~taufik/dchouse/publications.html. [Accessed: 24- Feb- 2017].

[3]. http://www.powerstream.com/Wire_Size.htm

[4]. http://www.dolphins-software.com/IEEE_ExactFormulae.htm

Appendix A - Analysis of Senior Project Design

Project Title: Smart Pathway Lighting System

Student's Name: Vineal Singh, Edith Rodriguez, Emily Whitaker

Student's Signature:

Advisor's Name: Taufik

Advisor's Initials: T

Date: June 16, 2017

- **Summary of Functional Requirements**

This project will provide a source of lighting at the Student Experimental Farm (SEF) as a pathway from the greenhouse to the DC House. This pathway lighting system consists of 12 light bulbs that have a PIR sensor attached to each bulb, all powered from the solar panels on the DC House. This sensor allows the system to know when a person is standing next to a bulb subsequently powering on that bulb, along with one bulb to the left and right of it.

- **Primary Constraints**

There were a few limiting factors to this project. Getting the proper components for this project showed to be a bit challenging. Since this is a DC system, 48V DC bulbs were required, along with a 48-48V DC/DC converter. Finding these bulbs and converters were difficult and expensive. Soldering the components was the next hurdle to overcome. Soldering such small components in such a small proximity proved to provide an unsuccessful outcome in our initial lab testing. Several shorts occurred as well as very poor connections. This was fixed by resoldering the original boards and redoing the boards that were too damaged to be repaired. Implementing this project out in the SEF was the final challenge in this project. The physical work of digging the trenches impacted our entire layout. The size of the pathway had to be decreased due to the level of difficulty that the digging to code presented. Once the pathway

size and location was determined and dug out, the wiring together all of the breadboards and components together posed the final issue. As there were so many different wires and limited space within each junction box, it was very difficult to make sure that all the wires were connected properly and securely.

• Economic

This project had a large impact economically. Costs and benefits were seen throughout the project with the majority at the end during implementation. This project requires the use of many different components of varying monetary value. The costs for this project were covered by the participant, the Electrical Engineering department, and our advisor. The original estimated cost of the system is displayed in Table 4-2, the final system cost is displayed in Table B-2 and the final bill of materials is displayed in Appendix C.

The final system implemented in the SEF is designed to exist indefinitely with proper maintenance. Maintenance costs may include, and are not limited to, replacing wires, bulbs, electronic components, and conduit fittings. The prices for these replacement items vary. The original estimated development time can be found in Appendix B in Figure B-1, and the actual development time can also be found in Appendix B in Figure B-2. Once this project is finished, it will be left to the SEF and Electrical Engineering community to improve and maintain this system.

• Commercial Basis

This project is not designed to be manufactured commercially. As it was created as an addition to the DC House and SEF, it was not intended to become a commercial product. However, in the event of another DC House project somewhere off of the grid, it can be encouraged to recreate this project if desired.

• Environmental

This project has some environmental impacts since there was no existing infrastructure for it to be built upon. There is a lot of wildlife out at the SEF, many of which burrow holes, such

as gophers, snakes, and squirrels. Since this project required trenches to be dug to 18 inches, there is a potential to negatively impact these animals by harming their underground pathways. There is also an abundance of trees in the vicinity whose roots were directly in the path and at the depth of our desired pathway. Unfortunately, we were forced to break the roots in order to run the conduit at a safe depth according to the NEC code.

The main feature of this project is the ability for the lights to only be on when a person is sensed on the pathway next to a bulb. With the lights only being on for seconds at a time as opposed to a traditional lighted pathway where lights are always on while it is dark, the amount of energy being consumed by the system is decreased. This project does not utilize any fossil fuels since it runs only off of solar power. By eliminating the use of fossil fuels in this project, the environment is not harmed by the side effects seen by burning these fuels.

• **Manufacturability**

There are not many challenges to be expected with manufacturing this project again. All components used for this project were readily available from manufacturers here in the United States and China and all were delivered in a timely fashion. The design of this project is simple to understand after viewing the testing and wiring schematics. The only challenge that would be seen is the physical implementation. With the proper tools and manpower the implementation could be relatively smooth.

• Sustainability

The maintenance of this system may prove to be challenging depending on where in the system is it needed. If the problem lies in the wiring within the conduit 18 inches underground, it will be difficult to get too and diagnose. If the issue lies within the wiring between components in the junction box, it should not be challenging to enter the junction box and diagnose the issue. This project runs off of solar power which is a very sustainable source of energy. Since the system is only powered on for seconds at a time there is no concern with a lack of power from the solar panels.

There are currently few upgrades available for this design. One upgrade would be to eliminate the need for two separate grounds for the 5V and 48V lines. If the grounds were tied together to one line, that would eliminate one wire being run through the conduit. Since there are so many wires required for this system, the elimination of even one 14 gauge wire will make the organization and wiring much more user friendly. The use of larger junction boxes would also prove to be a positive improvement. With larger junction boxes containing a larger depth, it will be easier for the wiring implementation and limit the margin for error in creating potential shorts or poor connections.

- **Ethical**

This project does not pose any ethical issues. All components would be the same price for the end user if this project were to be recreated. There is not an option to misuse this project in any way that could be seen as harmful or ethically problematic as long as proper health and safety concerns are met while manufacturing the system.

- **Health and Safety**

The main health/safety concern for the manufacturing of this project lies in the physical implementation. The use of power tools always poses a risk for injury which users must take into consideration before operating. While the trenching occurs, there should be proper precaution taken to clearly mark where the trench is in order to avoid the possibility of an individual to accidentally trip or step into the trench leading to injury. As with any electronic system, the risk of fire, electrocution, and/or shock is always apparent. This risk has been mitigated by the use of insulated wires throughout the system.

- **Social and Political**

This project impacts any individual at the SEF after daylight hours, or any individual or community who recreated this project in a rural area not connected to an AC grid. This system is not limited for utilization in rural areas, it can also be used in well populated and urban areas

such as the SEF. By eliminating the necessity for an AC grid, power companies will see impacts in their profit margins.

• Development

As part of the lighting pathway system installation, several procedures required by NEC had to be considered. The wiring of the system was made possible by running wires underground through the use PVC conduit. The regulations for burying electrical conduit require for the trenches to be 18 in deep. Being aware of this regulation, allowed our installation to adhere to NEC standards. In addition, methods and tools for conduit wiring were researched. To facilitate the wire pulling process tools such as fish tape were used. In addition, new methods for establishing electrical connection between wires were used such as using twist-on wire connectors instead of the conventional soldering of wires. Another important design detail we considered, was the sizing of wire for different loads through calculation. The overall design, introduced us to critical mechanical and electrical details.

Appendix B - Timeline of Tasks and Milestones

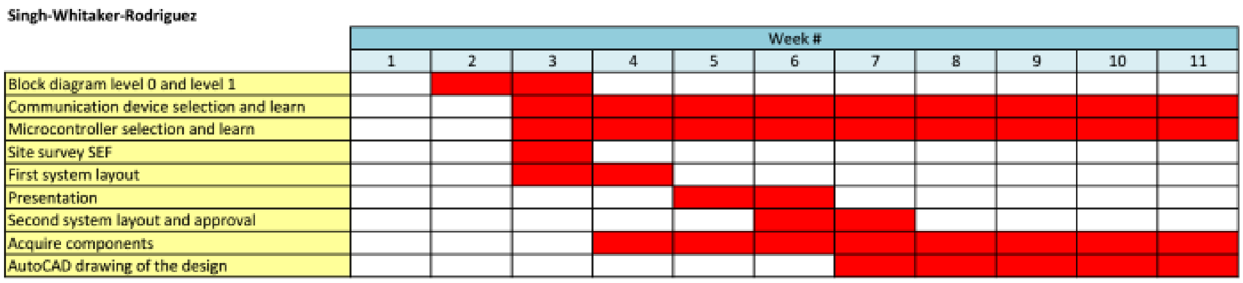

Figure B-1: Original Timeline of Tasks

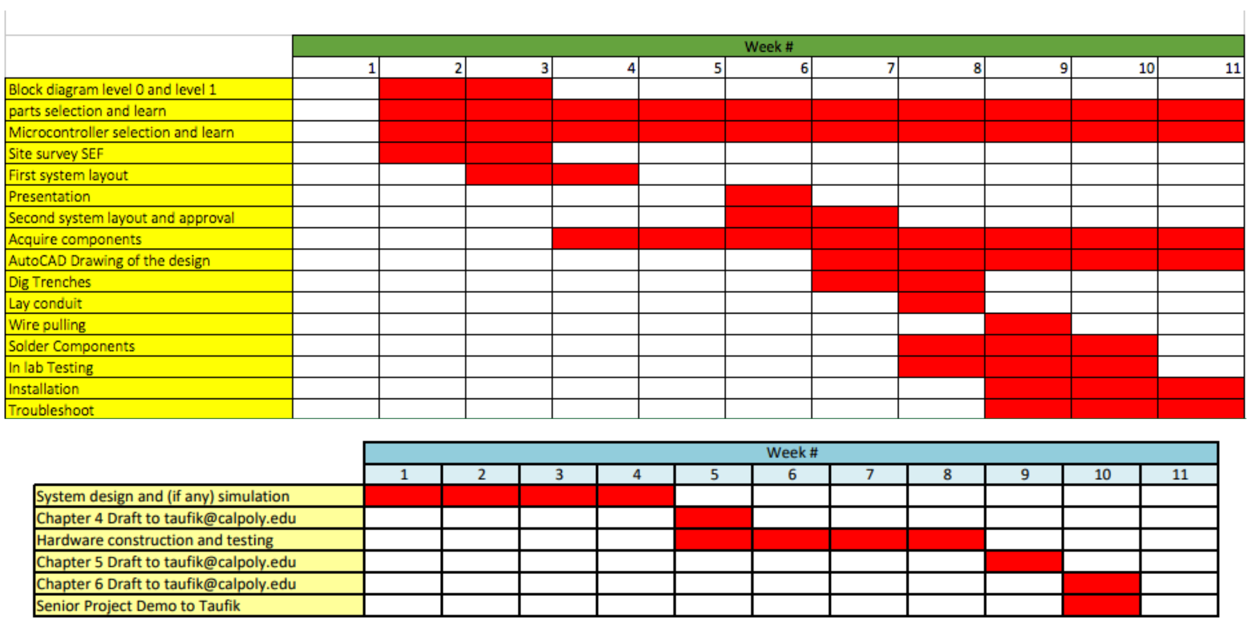

Figure B-2: Final Timeline of Tasks

Appendix C - Bill of Materials

Item	Quantity	Cost/Unit	Total Cost
48V DC Light Bulb	12	$3.5	$42
Light Bulb Sockets	12	$3.27	$39.24
3/4" PVC Conduit	15	$2.50	$37.50
Conduit Elbows	24	$0.82	$19.68
Wire Connectors(100 pc)	2	$9.97	$19.94
22 Gauge Wire(3 pack)	1	$9.94	$9.94
14 Gauge Wire(500 ft)	4	$34.37	$137.48
48-48V DC/DC Converter	0	$0	$0
48-5V DC/DC Converter	1	$9.60	$9.60
Junction Box	12	$5.49	$65.88
Junction Box Covers	12	$2.05	$24.60
PC Bread Boards	2	$5.00	$10.00
ProtoBoard	25	$0.52	$12.99
IC Socket Adapter	6	$0.79	$4.73
Arduino Uno Chips	6	$1.60	$9.61
PIR Sensor	12	$0.42	$5.04
NMOSFET	12	$0.68	$8.18
		TOTAL SYSTEM COST	$456.414

Appendix D - Microcontroller Code

```
**********************************************************************
* Project Name: SEF Light Path MCU code
*Group Names: Vineal Singh, Edith Rodriguez, Emily Whitaker
* Advisor: Taufik
* Date: 6/9/17
**********************************************************************
intledLeft = 6;               // left LED pin
int led = 9;                   // center LED pin
intledRight = 11;             // right LED pin
intsensorLeft = 4;            // left sensor pin
int sensor = 2;                // center sensor pin
intsensorRight = 0;           // right sensor pin
int state = LOW;               // by default, no motion detected
intval = 0;                   // variable to store the sensor status (value)
intvalLeft = 0;               // variable to store the left sensor status (value)
intvalRight = 0;              // variable to store the right sensor status (value)

void setup() {
 pinMode(led, OUTPUT);             // initalize LED as an output
 pinMode(ledLeft, OUTPUT);         // initalize LED as an output
 pinMode(ledRight, OUTPUT);        // initalize LED as an output
 pinMode(sensor, INPUT);           // initialize sensor as an input
 pinMode(sensorLeft, INPUT);       // initialize sensor as an input
 pinMode(sensorRight, INPUT);      // initialize sensor as an input
 Serial.begin(9600);               // initialize serial
}

void loop(){
 val = digitalRead(sensor);                 // read sensor value
 valLeft = digitalRead(sensorLeft);         // read sensor value
 valRight = digitalRead(sensorRight);       // read sensor value

 if (val == HIGH) {                         // check if the sensor is HIGH
   digitalWrite(led, HIGH);                 // turn LED ON
   digitalWrite(ledLeft, HIGH);             // turn LED ON
   digitalWrite(ledRight, HIGH);            // turn LED ON
   delay(400);                              // delay

   if (state == LOW) {
     Serial.println("Motion detected!");          // used for testing purposes
     state = HIGH;                                // update variable state to HIGH
   }
 }

 else if (valLeft == HIGH){
   digitalWrite(led, HIGH);           // turn LED ON
   digitalWrite(ledLeft, HIGH);       // turn LED ON

    if (state == LOW) {
     Serial.println("Motion left detected!");       // used for testing purposes
     state = HIGH;                                  // update variable state to HIGH
   }
```

```
 }

 else if (valRight == HIGH){
   digitalWrite(led, HIGH);              // turn LED ON
   digitalWrite(ledRight, HIGH);      // turn LED ON

    if (state == LOW) {
     Serial.println("Motion right  detected!");       // used for testing purposes
     state = HIGH;                                              // update variable state to HIGH
   }
 }

 else {
     digitalWrite(led, LOW);              // turn LED OFF
     digitalWrite(ledRight, LOW);     // turn LED OFF
     digitalWrite(ledLeft, LOW);       // turn LED OFF

     if (state == HIGH){
       Serial.println("Motion stopped!");     // used for testing purposes
       state = LOW;                                    // update variable state to LOW
   }
 }
}
```